SPERRY PRODUCTS

DIVISION OF AUTOMATION INDUSTRIES, INC.

Sperry

DANBURY, CONNECTICUT

FINAL REPORT

ON

ULTRASONIC SURFACE WAVE PROBING TECHNIQUES FOR DETERMINING MATERIAL SOUNDNESS

Prepared for:

GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA
Contract No. NAS8-11454

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II INTRODUCTION

Sheet and plate metal form an essential and integral part of major structural components and assemblies in space vehicle stages. Use of unsound material could seriously jeopardize flights because of unreliable strength assumptions. Lack of soundness becomes more acute, or actually begins to exist, as a result of working the material. Therefore, methods for detecting and locating surface defects are required in the preassembly phases of stage fabrication.

Methods presently used include fluorescent dye penetrant, visual inspection, and others of lesser popularity. All of these methods are time consuming and are quite subject to human error. Further, the dye penetrant method, although comparatively accurate, adds a clean-up problem in the removal of the dye; this is especially difficult in small cracks and becomes critical where "lox" cleanliness is involved.

Ultrasonic methods of inspection have become fairly common in recent years. Work has been done at MSFC which demonstrates the accuracy and the reliability of weld inspection by ultrasonic methods, and also demonstrates unique capabilities not possible by other means. Generally, these techniques use a shear wave approach. An angle beam shear wave method has the characteristic of probing through the material of a plate in a zig-zag path along the plate, alternately reflecting from its two sides. Thus, both sides may be scanned in one operation. A shallow crack at one side would form a corner reflector; the material surface acting as one face, and the crack as the other face of the corner reflector. Both flat plate and contoured plate may be inspected by this method. However, the operation of this method may be seriously complicated by irregular geometry of the opposite side, or by attachments made to the opposite side. It is in such cases that the use of a surface wave method has a distinct advantage.

Unlike shear wave propagation as described above, surface waves penetrate only to a very limited depth into the material, and travel along the contour of the material until interrupted by a sharp change in surface direction. A natural edge of the material or a very shallow discontinuity in the material would present such a change in direction.

Surface wave propagation requires a material thickness of at least one wavelength of the surface wave. Thinner material will not support surface waves; instead, the thinner material would cause Lamb waves to be generated. Propagation of surface waves is only slightly attenuated in aluminum having smooth faces. These characteristics make the use of a surface wave method especially suitable for the inspection of large areas of a single surface of either flat or gently contoured aluminmm plate.

III SCOPE OF WORK

This is to consist of a study to determine the feasibility of using an ultrasonic surface-wave inspection system for saturn structural components. This study should include an investigation to determine all commercially available ultrasonic surface-wave equipment which could be applicable to this task.

If the surface-wave inspection technique is found to be feasible for use as described above, investigate the feasibility of designing an automated scanning system for parts generally of formed panels approximately 16 feet square in the thickness range 0.091 to 1 inch and contoured to approximately a 33 foot spherical diameter; and specifically, parts in the size and shape of the Saturn S-1C-T gore segments (MSFC Drawing J-60B12102).

The results of both studies will be combined into one final report and submitted to MSFC. This report shall include findings, conclusions, and recommendations based on the studies. The report shall also include drawings and sketches illustrating a sample system based on data from the studies.

IV DETAILED WORK PROGRAM

Step 1 - Application Feasibility:

The contact angle beam surface wave search units will be used to determine their applicability to the detection of the required surface discontinuities. Frequencies of 1.0, 2.25, and 5.0 Mc will be used on raw and worked metal at Saturn fabrication sites.

Step 2 - Reference Standards:

Reference plates of materials to be surface wave inspected in the Saturn assembly will be selected from trimmed material at the fabrication sites during Step 1. Square edge notches of four different depths will be machined into these plates to provide reproducible, artificial surface wave reflectors. Depths of the notches will be adjusted to simulate signal amplitudes found in Step 1 at the appropriate test frequency.

Step 3 - Study of Waves Generated by the Variable Angle Wheel Search Unit:

Three standard side angle variable angle ultrasonic wheels will be modified to provide the test frequencies of 1.0, 2.25, and 5 Mc and optimized for the production of surface waves. Distance amplitude curves will be taken on the surface wave reference plates produced in Step 2, to simulate surface defects at different test distances.

During the application feasibility study (Step 1), it may be found that there are inaccessible surfaces opposite the test surface which cannot be readily inspected by surface wave techniques. If it is desirable to inspect these surfaces, we will study angle beam shear waves generated by the variable angle wheel search units at 1.0, 2.25, and 5 Mc test frequencies to determine optimum beam angles for this inspection. Amplitude distance curves will be made.

Step 3.A. - Alternate Study of Randomly Oriented Surface Defects:

It is believed that during Step 1 we will find the defects oriented in one or possibly two directions. This condition will permit detection, location, and measurement of these reflectors by one or two inspecting passes with the variable angle wheel search unit. However, if defects of random orientation must be found, numerous scans of the material would be required to provide complete coverage with the established surface wave beam.

In order to avoid multiple scans at different beam orientations, we will develop a special ultrasonic wheel which will radiate surface waves in all directions from its contact position on the aluminum. This 360° surface wave generator may be accomplished by using a circular crystal with a conical reflector or refractor. The conical angle would deflect the beam to the appropriate incident angle to produce surface waves while the cone would spread the beam over three hundred sixty degrees.

A scanning system using this wheel might be gated to inspect a ring of surface around the wheel as it travels across the surface. For example, gating from 4 to 8 inches from the wheel centerline might provide inspection of an 8 inch I.D. 16 inch O.D. ring. Parallel scans at 4 inch increments would be required (for this example) to provide complete inspection for randomly oriented surface defects.

Step 4 - Distance Amplitude Correction, Gating, and Recording:

The DAC module will be used to determine the width of the test swath which can be taken across the material with one pass of the ultrasonic wheel. The DAC module permits correction to equalize signal amplitudes from equal sized reflectors without a change with distance. This in turn permits the use of long gating periods with the assurance that minimum triggering reflectors will be of equal size and will not vary with distance.

Recordings of the reference plates will be taken using DAC and the long gate with a manually moved Ultrasonic Wheel.

Step 5 - System Layout:

A surface wave scanning system layout drawing will be made. The shapes of Saturn structural parts and the orientation of surface cracks on these parts will to a large extent determine the complexity of the scanning system. System design will be carried to a stage sufficiently advanced to permit our estimation of the cost of the final Surface Wave System.

V WORK PERFORMED AND RESULTS OBTAINED

Step 1 - Application Feasibility

Visits were made to Huntsville, Alabama and to Wichita, Kansas to gather information on test variables which might affect the surface wave study, and to survey typical plate specimens to be inspected.

Seven surface wave test plates were requisitioned. These represent specimens in two aluminum alloys, in several surface finishes, and in a variety of thicknesses.

Upon receipt of the first of these specimen plates in Danbury, contact tests using wedge type surface wave search units were conducted to determine the feasibility of generating and receiving surface waves in the material. At 1.0 Mc, 2.25 Mc, and 5.0 Mc results indicated that true surface waves could be produced in the specimen material and that effective testing for surface defects could be accomplished by hand scanning.

An ultrasonic variable angle wheel search unit was then applied to the same specimen and was adjusted to generate a surface wave at 2.25 Mc. Results of this test agreed with those of the wedge type search units. The ultrasonic wheel search unit is ideally suited to automatic scanning since it easily adapts to changing surface contours, uses a minimum amount of couplant, and will perform rapid testing without appreciable wear.

In consideration of these results, the variable angle wheel type search unit was selected for further tests on the specimen material. Additional variable angle wheel search units in frequencies of 1.0 Mc and 5.0 Mc were prepared and made available for the project.

Step 2 - Reference Standards

Seven test plates, designated "A" through "G" were delivered to Sperry Products Co. in Danbury, Conn. for use as laboratory specimens for the project. Basic dimensions, composition and surface finishes of these plates are given in Table I.

TABLE I

SURFACE WAVE TEST PLATES

2219-T37 Aluminum Alloy Flat 24 x 30 in. Plates
1/4 in. Thick Except As Noted

	Surface	Special Feature	Source	Figure No.
A.	As rolled	Trimmed material per BMS7-105	NASA Boeing, Wichita	1
B.	Mill, sand & Alodine	.010 in. taper per inch from .600 at one 24 in. long edge to .300 at the other edge.	NASA Huntsville	2
C.	Mill, sand & Alodine	.010 in. taper per inch from .350 at one 24 in. long edge to .050 at the other edge	NASA Huntsville	2
D.	One side chem. milled, other milled & sanded	Surface conditions	NASA Huntsville	3
2219-T87 Aluminum Alloy Flat 1/4 in. Thick 24 x 30 in. Plates				
E.	Milled & sanded over-all, 1/2 of the length Alodine	Surface condition	NASA Huntsville	4
F.	Mill, sand	Thickness variation	NASA Huntsville	5
2219-T87 Aluminum Alloy Formed 24 x 30 Section of Core Segment				
G.	Final finish	Contour	NASA Huntsville	6

Step 3 - Study of Waves Generated by the Variable Angle Wheel Search Unit

Work under this step, using variable angle wheel search units were divided into the following three parts.

A. Determination of conditions required for optimum generation of surface waves in specimen material.

B. A study of wave types generated in specimen material with special attention given to identification and comparison of surface waves and lamb waves.

C. A study of surface wave propagation in specimen materials.

Step 3-Part A

1. Surface waves, produced by mode conversion from the longitudinal at an angular interface, will attain maximum practical amplitude when the coupling device contacts the work at the incident interface and not in front (beam direction) of this position. Figure 8 illustrates two techniques of providing optimum surface wave coupling with the variable angle wheel. Variation of tire contact width or moving the crystal inside the wheel (simulated in our study by deflecting the tire) provides equally effective results as shown in Figure 9 2 to 2 1/4 inch amplitude surface wave signals can be maintained by controlling the tire contact width between 1 and 1 1/4 inches without side deflection or between 3/4 and 1 1/2 with the crystal moved (side deflection of tire) 1/32 to 1/4 inch depending on tire contact width.

The three variable angle wheel search units (1.0 Mc, 2.25 Mc and 5.0 Mc) were ultrasonically coupled to test plate "A" as shown in Figures 10, 11, and 12 and their side angle controls were adjusted to maximize the amplitude of surface wave transmission to, and reflection from a sharp edge of the plate. In each test, tire surface contact width was varied by moving the wheel axis toward or away from the plate. The amplitude of the received surface-wave signal and of the relative wheel axis position (Post Height) were recorded and were plotted as functions of tire surface contact width.

These plots, also shown in Figures 10, 11, and 12 indicate that the following tolerances in wheel axis to plate surface distance are required for use of peak signal amplitude and a signal amplitude tolerance of ± 10%:

Wheel Search Unit			Tolerance Inches, Post Height
Style	Serial	Freq. Mc	
50D403	T-1719	1.0	± 0.090
50D340	T-1723	2.25	± 0.050
50D404	T-1720	5.0	± 0.060

2. Surface wave tests were run at 1.0 Mc, 2.25 Mc, and 5.0 Mc using Variable Angle Wheel Search Units on Test Plate "E" to determine angular tolerances required in a positioning system.

The method of tests and the results obtained are shown in Figures 13 and 14. In each of these tests, the Forward/Backward control was set for a 0° angle, the side angle wheel control was run through its range for surface wave generation, and the amplitudes of signals reflected from the notch were read. Incident angles corresponding to side wheel control settings are taken from the graph in Figure 7.

Angular tolerances required to maintain signal amplitudes within the top 10% are given below.

Frequency Mc.	Angular Tolerance Degrees
1.0	± 1.4
2.25	± 0.8
5.0	± 0.5

3. Surface wave tests were run at 1.0 Mc, 2.25 MC, and 5.0 Mc using variable angle wheel search units on test plate "E" to determine signal amplitude - reflector orientation relationship.

The method of tests and the results obtained are shown in Figure 15. In each of these tests, the forward/backward control was set for a 0° angle, the side angle wheel control was adjusted to produce a maximum amplitude surface wave, the wheel was turned through angle "A", and amplitudes of signals reflected from the notch were read.

Results indicate that orientations of reflectors at a distance of 12" must be within the following ranges to maintain signal amplitudes within the top 10%:

Frequency Mc.	Angular Tolerance of Reflector Degrees
1.0	± 1.1
2.25	± 0.5
5.0	± 0.5

4. Variable Angle Wheel Search Unit Tests were run at 1.0 Mc, 2.25 Mc, and 5.0 Mc to determine the effect of search unit cable length on signal amplitudes.

   In these tests, a reflected signal of 2.0" amplitude was set up using a 6 ft. 4 in. cable attached to the "T" jack of the reflectoscope. Cable lengths were varied and attachments were made to either the "T" or the "R" jacks.

   Results are given in Figure 16.

Step 3 - Part B

1. Precision velocity measurements of surface wave propagation in specimen plates "A" and "G" were made at 1.0 Mc, 2.25 Mc, and 5.0 Mc by the method illustrated in Figure 17. In these contact angle beam search units and a velocity comparator, style 52B012 were used. Results are also given in Figure 17. Interferences from other modes was noticed in the measurement at 1.0 Mc on the 1/4" thick plate, and for this reason the indicated value has a wide tolerance.

2. A detailed study was conducted of waves generated in specimen material by variable angle wheels at test frequencies of 1.0 Mc, 2.25 Mc, and 5.0 Mc.

   Identification of the several types of waves was made by measurement of the incident angles required to produce them and of their group velocities along the specimen plates. Incident angles corresponding to observed Side Wheel Control Settings were taken from the graph in Figure 7. The method used in group velocity measurement is illustrated in Figure 18.

Phase velocities were computed by the method given in Figure 19.

Shear wave and longitudinal wave transmission along zig-zag paths in plates of thicker sections was recognized by the compliance of an observed velocity to the theoretical velocity parallel to the plate surface as computed from the method given in Figure 20.

Surface wave transmission was recognized by its velocity of 2.90×10^5 cm/sec. (1.14×10^5 in./sec.) as given above, an incident angle of 35° corresponding to Side Wheel Control Setting of 19.80 and by the ability to damp transmission in thicker plates from one side only by placing one's hand along the path of the beam.

Lamb wave transmission was recognized by phase and group velocities both agreeing with computed values for test frequency - plate thicknesses as given in Figures 21, 22, 23, and 24. As shown by these curves, of the many modes of Lamb wave propagation possible, only the first modes can be generated in very thin plate. Therefore, this mode was used as a reference to determine the point at which reduction of plate thickness would preclude transmission of surface waves.

Results of tests are given in Figure 25. In this, the theoretical curves for first mode group velocity and phase velocity against plate thickness are reproduced, and observed data are plotted for comparison. Examination of Figure 25 shows a good correlation of observed data to theoretical values. Further examination shows that surface wave propagation can be obtained in specimen material not less than the following thicknesses:

0.125"	at	1.0 Mc
0.056"	at	2.25 Mc
0.025"	at	5.0 Mc

At thicknesses below these values surface waves disappear.

Step 3 - Part C

1. Surface wave tests were run at 1.0 Mc, 2.25 Mc, and 5.0 Mc using variable angle wheel search units on Plate "A" to determine the effects of notch depth from the surface, and of notch depth below the surface, on amplitude of reflected signals.

   For the surface notch tests, the search units were setup as shown in Figure 26 with the surface wave beam directed toward a tapered surface notch. Sensitivity was adjusted to produce a 2.0 inch signal from the edge of the plate with no notch in the beam. The search units were moved parallel to the tapered notch and amplitude of signals from both the notch and the edge of the plate were read. Plots of the data obtained are given in Figure 26.

   For the subsurface notch tests, plate "A" was turned over as shown in Figure 27. Sensitivity was adjusted to produce a 2.0 inch signal from the notch at a position where the notch cut entirely through the plate. The search units were moved parallel to the notch so that depth distance "D" increased, and the amplitudes of signals reflected from the notch were read. Plots of data obtained are given in Figure 27.

2. Tests were run at 1.0 Mc, 2.25 Mc, and 5.0 Mc using variable angle wheel search units over plate "A", "B", "D", "E", and "G" to determine the effect of plate finish and plate material on the propagation of surface waves.

   In these tests the search units were setup to direct their beams toward notches of various depths in plates having notches, and toward plate edges as shown in Figure 27. Sensitivity was adjusted to produce a 2.4 inch reflection from the edge of plate "A".

   Signal amplitude/depth of notch data for the three frequencies, with plate condition as a parameter, are given in Figures 28 and 29. Non-uniform sharpness of the edges of the several plates contributed largely to the spread of values at the ± .250 inch points.

3. Surface wave tests were made at 1.0 Mc, 2.25 Mc and 5.0 Mc using variable angle wheel search units on the concave side of contoured plate "G" as at point "A" in Figure 6, with the beam directed toward point "B".

   Large and very irregular signals were produced in the screen; certain of which were identified as direct reflections from abrupt edges formed by the contouring of the plate. Others were identified as reverberations between such edges.

   As wheel units were rolled along line CD, the positions of such irregular reflections changed rapidly and no clear reference pattern was recognized for inspection areas beyond the first abrupt break in contour.

   Similar tests were run on contoured plate "G" with the variable angle wheel search units adjusted to produce shear waves in zig-zag paths through the material alternately reflecting from the two surfaces. Again, the irregular geometry of the specimen caused large and very irregular signals to be produced on the screen which generally were difficult to interpret.

Step 3A - Alternate Study of Randomly Oriented Surface Defects

This step had been entered in the "Detailed Work Program" as an optional phase and had been quoted as an additional cost study. The contract for the project did not originally include this step; and since it was not covered by contract amendment, no work was performed applying to it.

Step 4 - Distance Amplitude Correction, Gating, and Recording

1. Surface wave tests were run at 1.0 Mc, 2.25 Mc, and 5.0 Mc using variable angle wheel search units on test plate "E" to determine distance-amplitude characteristics of surface wave transmission, and to demonstrate Distance-Amplitude-Correction by use of a DAC module.

   The method of tests and the results obtained are given in Figures 30 and 31. In these, the Forward/Backward Control was set for 0°, the Side Wheel Control was set for a peak amplitude surface wave reflection from the notch, distance D from centerline of the tire to the slot was varied, and with DAC switched OFF the signal amplitudes were read.

The DAC module was then switched ON and was adjusted to produce, as closely as possible, a flat response with distance D again varied.

Results show that the DAC module provides amplitude correction to a tolerance of $\pm$ 5% for surface wave signals reflected from a given notch throughout the following distance ranges in specimen material.

Test Frequency Mc	Effective Distance Range Inches
1.0	5 to 25
2.25	2 1/2 to 25
5.0	2 1/2 to 25

2. Tests were made using a Transigate 50E550 with the Reflectoscope and Variable Angle Wheel Search units at 1.0 Mc, 2.25 Mc, and 5.0 Mc, on specimen plate "E" to determine whether surface wave reflections from the notch 0.013" deep in the distance range of 1 to 25 inches could be gated.

   Results show that such gating can be accomplished for each of the three Wheel Search Units. A Reflectogram illustrating a typical screen pattern is given in Figure 32. In this, the gate is set to cover the range of 1 to 25 inches from the tire centerline. The reflected signal from the notch 24 inches away falls within the gate and is therefore available for operation of recording and alarm systems, whereas the initial pulse, and the signal reflected from the end of the plate fall outside the gate and are excluded from recording and alarm systems.

3. Tape recordings were made of surface wave signals reflected from the 0.013" slot in plate "E" as the variable angle wheel search units were rolled parallel to the slot. In travelling the full 12" length of the slot, the surface wave beam was successively transmitted across a plain milled and sanded surface; and a milled, sanded and Alodine surface.

   A typical recording is given in Figure 32. This shows excellent detection of the notch along its full length with no appreciable difference in signal amplitude for the two surface conditions.

For this test, a Transigate 50E55 module was plugged into the "Auxiliary" compartment of a Reflectoscope UM-50B721, and a Brush Recorder (Mark II, Model RD-2522-20) was connected to Terminal #21-J-103 of the Reflectoscope Display Unit.

4. Tests were run using the same Reflectoscope, Recorder and Search Unit equipment as in above tests to determine amplitude linearity of the Recorder output as referred to the amplitude of a single gated signal on the Reflectoscope screen. Such system involves, of course, the Transigate module.

   To do this, a Wheel Search Unit was set to direct a Surface Wave toward the 0.013" notch in plate "E"; the Reflectoscope Sensitivity was adjusted to show the reflected signal 2 inches high on the screen; and the pen bias and sensitivity controls of the recorder were adjusted to produce a full scale (40 Mm) pen deflection on the tape. The wheel was then run parallel to the slot until slightly past the end so that the screen signal was successively reduced to 1.5, 1.0, 0.5, and 0 inches.

   The resulting record as given in Figure 32, indicates very good amplitude linearity of the Transigate-Recorder system.

Step 5 - System Layout

A surface wave scanning system was designed as shown in Sperry Drawing 52D311 "Proposed System for Surface Wave Inspection". See Figure 35.

This permits scanning of a 16 ft. by 16 ft. specimen by automatic reciprocating carriage drive at 30 ft./min., and manually indexing. Previous tests have shown that an indexed increment of 2 ft. is practical for this system.

A variable angle wheel search unit is mounted on a self-positioning carriage which follows the contour of the specimen, Sufficient couplant is fed to the TIRE to maintain optimum coupling.

Instrumentation consists of the following components:

Reflectoscope UM-50B721 with Pulser/Receiver 5N and Transigate 50E550.

Note: Pulser/Receiver 5N operates at 1.0 Mc, 2.25 Mc and 5.0 Mc.

2nd deck - UM710 with DAC and "S" Chassis

3rd deck - Single channel strip chart recorder and system control

A rotating support member holds the specimen in place for inspection. Orientation of scan may be controlled by rotation of the support member.

It is essential that the self positioning carriage mounting a variable angle wheel search unit for surface wave testing, align itself within angular tolerances and maintain the distance between wheel axle and test specimen within tolerances found in Step 3, - Part A.

On either flat or spherical surfaces, this is no real problem. However, in the case of an ellipsoidal surface, the various curvatures encountered may produce positioning errors beyond allowable tolerances.

The factors involved are illustrated in Figure 33.

A theoretical treatment of the problem for the specific case of the ellipsoid described on MSFC Drawing J-60B12102 and two wheels of a carriage spaced 8 inches apart is given on Figures 34 and 35. This case is taken with one wheel at the edge of the plate (coordinates 144, 96.094) where curvature is maximum, and positioning errors, as referred to a setup on flat plate are also maximum.

Maximum errors so derived, are compared here with tolerances determined experimentally:

	Theoretical Values	Experimental Tolerance
Compression of tire	0.024 inch	$\pm$ 0.050 Inch*
Angle of tire	0.28 min.	$\pm$ 0.5 degree**

* for 2.25 Mc Wheel
** for 5.0 Mc Wheel

The theoretical values fall well within minimum experimental tolerances.

Tests conducted inidcate that use of a search unit cable 25 feet in length, as required by the scanning system, reduces operating sensitivity below levels obtained with a 6 ft. 4 in. cable length by such small amounts that compensation can easily be made by increased instrument sensitivity settings. See Figure 16. In these tests the highest instrument sensitivity setting used was 1 x 1; whereas a maximum setting of 10 x 10 or an increase of 100 times, is available.

VI CONCLUSIONS

1. The "Proposed System for Surface Wave Inspection" described in Section V of this report is suitable for scanning aluminum plate or formed panels of smooth contour approximately 16 feet by 16 feet in the thickness range of 0.091 to 1 inch and contoured to approximately 33-foot spherical diameter; or specifically the convex surface of a GORE, APEX-UPPER HEAD OXIDIZER TANK for the Saturn S-1C-T assembly. (See MSFC Drawing J-60B12102.)

2. The time required for inspection of a 16 ft. by 16 ft. specimen with a surface wave beam in a single azimuth is determined by the automatic carriage scan rate of 30 ft./min., the indexing interval of 2 feet, and the period for each indexing operation of 15 seconds.

Time per scan	32 seconds
Number of scans	8
Scanning time	256
Indexing time	120
Total inspection time	376 seconds

   Specimens smaller than this maximum size would, of course, require shorter inspection times. Indexing intervals smaller than 2 feet may be used if required. A tape record is made of signals appearing in each scan.

3. The surface wave inspection method is very directional. Variation in test notch orientations in the range of ± 0.5 degree reduces a reflected signal amplitude 10% below its maximum value.

   In practice, material flaws, as reflectors, are commonly found to encompass a much wider angular range than this and therefore are more easily detected than a machine-cut notch.

   Initial tests of a specimen should be conducted with the "Rotating Support Member" adjusted so that the most probable orientation of natural flaws is normal to the surface-wave beam direction.

4. Surface waves can exist in specimen materials of not less than the following thicknesses:

Frequency Mc.	Thickness Inches
1.0	0.125
2.25	0.056
5.0	0.025

5. Experimental surface-wave tests show that surface features on the side opposite the testing side seriously interrupt the beam when material thicknesses are below the following values:

Frequency Mc	Thickness Inches
1.0	0.245
2.25	0.055
5.0	0.040

6. Surface-wave tests on specimen material indicate that signals of sufficient amplitude for the reliable operation of a recording system are produced by notches of the following depths in the distance range of 2 1/2 to 25 inches.

Frequency Mc	Depth Inches
1.0	0.027
2.25	0.007
5.0	0.008

7. Only small differences were observed in the relative attenuation of surface wave propagation in specimens of two materials having five different finishes.

   Equalization of testing sensitivity can easily be accomplished for the several material conditions by small adjustments of the Reflectoscope "Sensitivity" control.

8. The Distance-Amplitude-Correction (DAC) module provides amplitude correction to within a tolerance of $\pm$ 5% for surface wave signals reflected from a given test notch throughout the following ranges in specimen material:

Frequency Mc	Distance Range - Inches
1.0	5 to 25
2.25	2 1/2 to 25
5.0	2 1/2 to 25

9. A surface wave inspection method applied to the side of a specimen containing many bosses, ribs, slots, or holes results in very irregular screen patterns.

In such cases, automatic inspection is limited to clear areas large enough to accommodate the self-positioning carriage; and further, to scanned areas between the tire of the search unit and the first abrupt break in contour encountered by the surface-wave beam.

In the case of specimens having only a few such interfering surface features, automatic inspection results can be interpreted by "reading out of the record" signals known to come from these normal features.

10. A shear-wave inspection method applied to either side of a specimen containing irregular surface features on one or both sides results in irregular screen patterns.

VII RECOMMENDATIONS

The feasibility of using an ultrasonic surface-wave system for the inspection of SATURN structural components has been demonstrated in a series of tests on small area specimens containing controlled simulated defects.

The following steps are now recommended:

1. Complete design of the automatic ultrasonic inspection system illustrated in "Proposed System for Surface Wave Inspection", Sperry Products Drawing 52D311.

2. Construct the "System" in accordance with final design. Install instrument package as described on Sperry Products Drawing 52D311.

3. Prepare "Rotating Support Member".

4. Prepare ultrasonic reference plate as shown in Figure 37.

5. Use completed "System for Surface Wave Inspection" in performing the following tests:

   a) Detect and record simulated defects in full size specimens in static tests (automatic drive turned off).

   b) Detect and record simulated defects in full size specimens in dynamic tests (automatic drive turned on).

   c) Compare results of (a) and (b).

   d) Detect and record natural defects in both static and dynamic tests. Compare results.

   e) Measure size of natural defects by means other than ultrasonic. (Note: This may use a destructive method.)

   f) Establish correlation between recorded ultrasonic signals from both natural and simulated defects and their location and size.

   g) Establish standard of ultrasonic operating sensitivity in testing through the use of a reference plate. See Figure 37.

VIII ILLUSTRATIONS

IX APPENDIX

A. Work Performed During Final Period

During the final period of this project, the following work was performed:

1. Studies made as described in Final Report; and corresponding illustration number:

a) Beam, Direction	Fig. 15
b) S.U. Cable Length	Fig. 16
c) Amplitude/Depth of Notch	Fig. 26
d) Sub Surface Notch	Fig. 27
e) Surface Finish	Figs. 28, 29
f) S.U. Alignment	Figs. 33, 34, 35

2. System layout was completed as described in Final Report and illustrated in Fig. 36.

3. Reference Test Plate was designed. See Fig. 37.

4. The Final Project Report was prepared and issued.

B. NASA Property

At the close of this project the following items, all property of NASA, are on hand at Sperry Products, Danbury, Conn.

Quantity	Description
1	Variable Angle Wheel Search Unit Type SOB, Freq. 1.0 Mc., Size 1/2 x 1 Style 50D403 Serial T-1719
1	Variable Angle Wheel Search Unit Type SOB, Freq. 2.25 Mc., Size 1/2 x 1 Style 50D340 Serial T-1723
1	Variable Angle Wheel Search Unit Type SOB, Freq. 5.0 Mc., Size 1/2 x 1 Style 50D404 Serial T-1720
7	Aluminum Specimen Plates designated A to G and illustrated in Figures 1 to 6 inclusive of the Final Report

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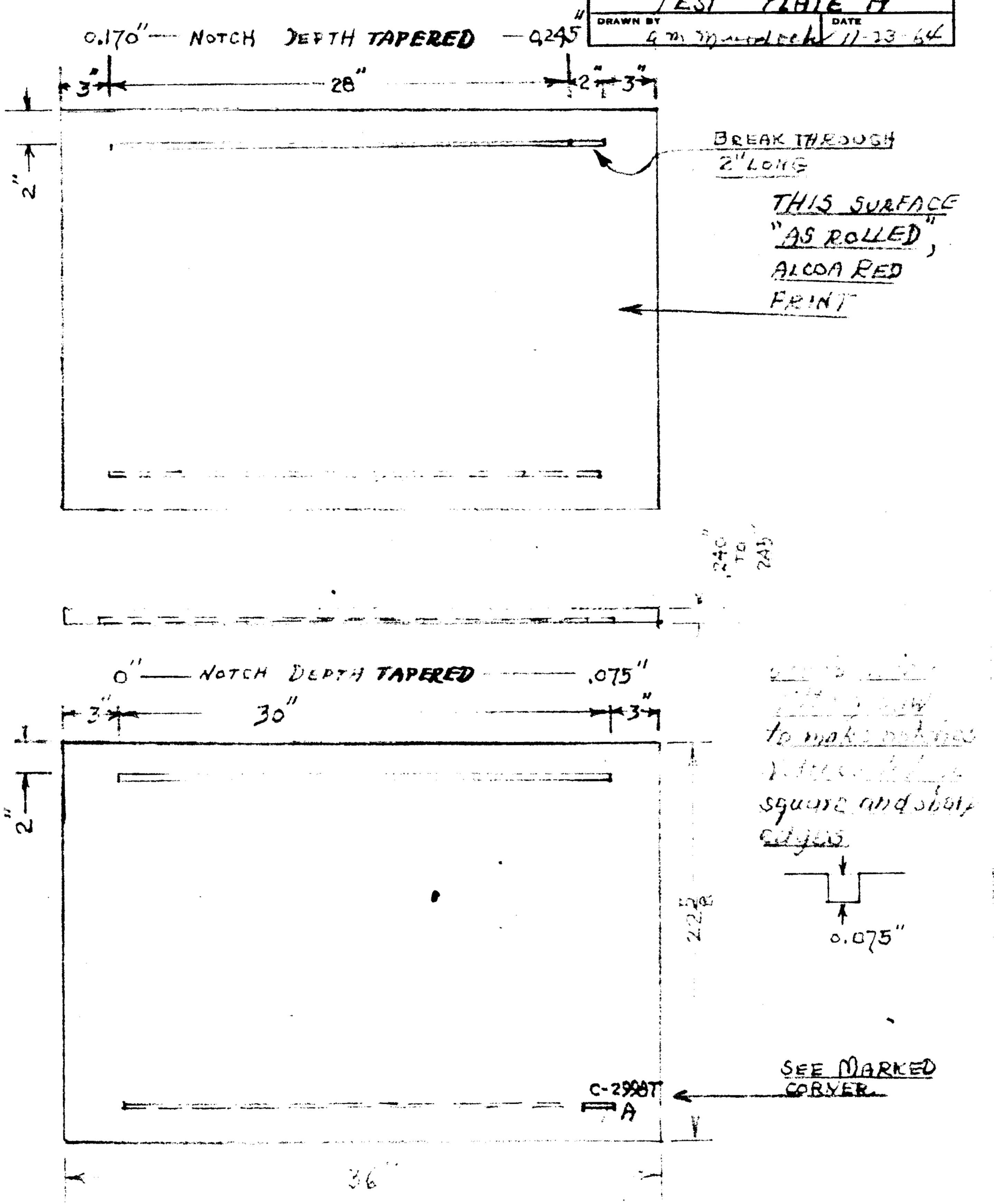
SKETCH SHEET

SKETCH NO. 1	FILE REF. C-2998-T
CUSTOMER NASA	
ADDRESS	
TITLE TEST PLATE "A"	
DRAWN BY G. M. Murdock	DATE 11-23-64

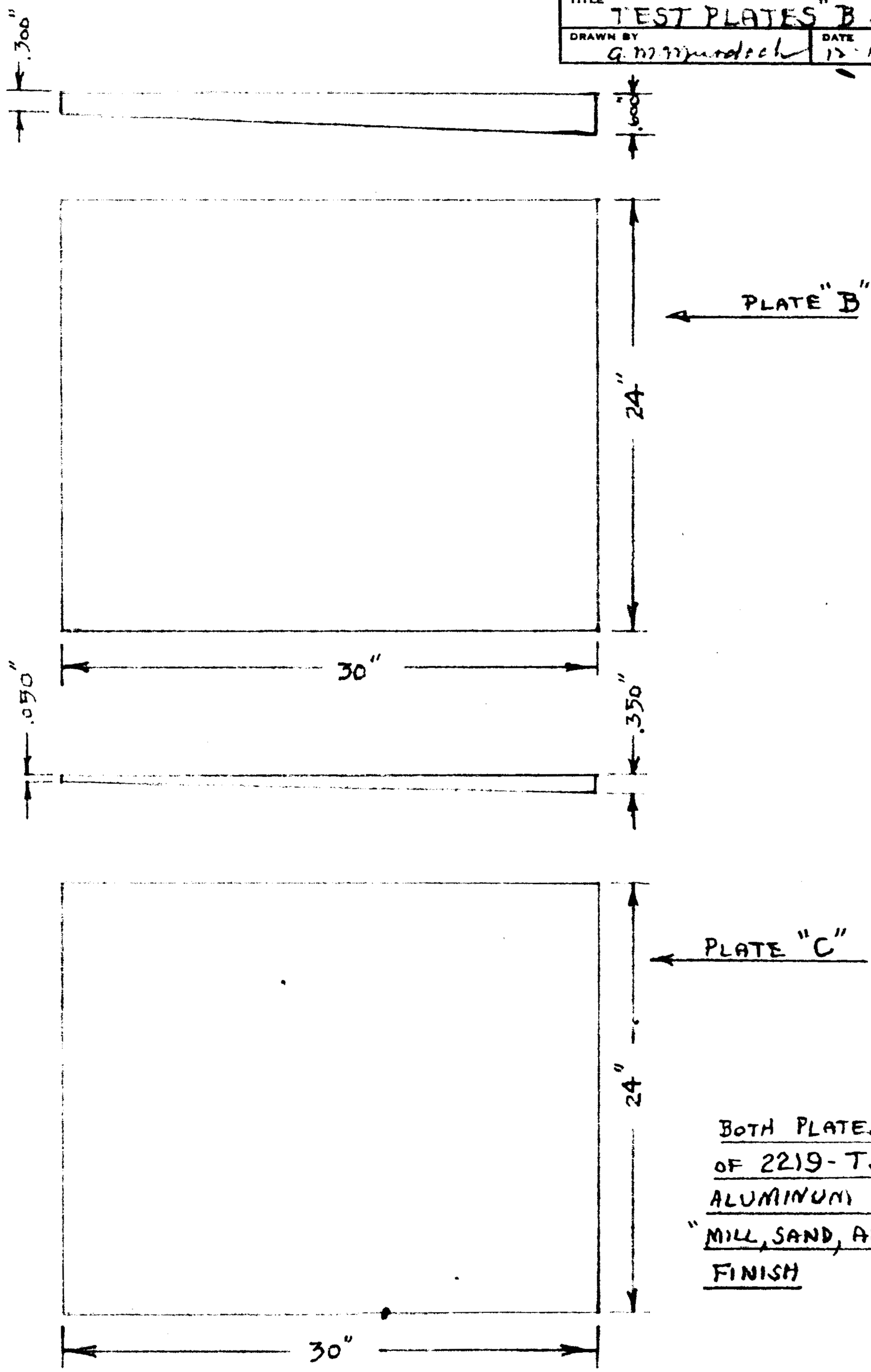


MATERIAL
ALUMINUM 2219-T37

FORM 1.41

SPERRY PRODUCTS
DIVISION OF AUTOMATION INDUSTRIES, INC.
SKETCH SHEET

SKETCH NO. 2	FILE REF. C-2998-T
CUSTOMER NASA	
ADDRESS	
TITLE TEST PLATES "B" AND "C"	
DRAWN BY G. M. Murdock	DATE 12-17-65



BOTH PLATES
OF 2219-T37
ALUMINUM WITH
"MILL, SAND, ALODINE"
FINISH

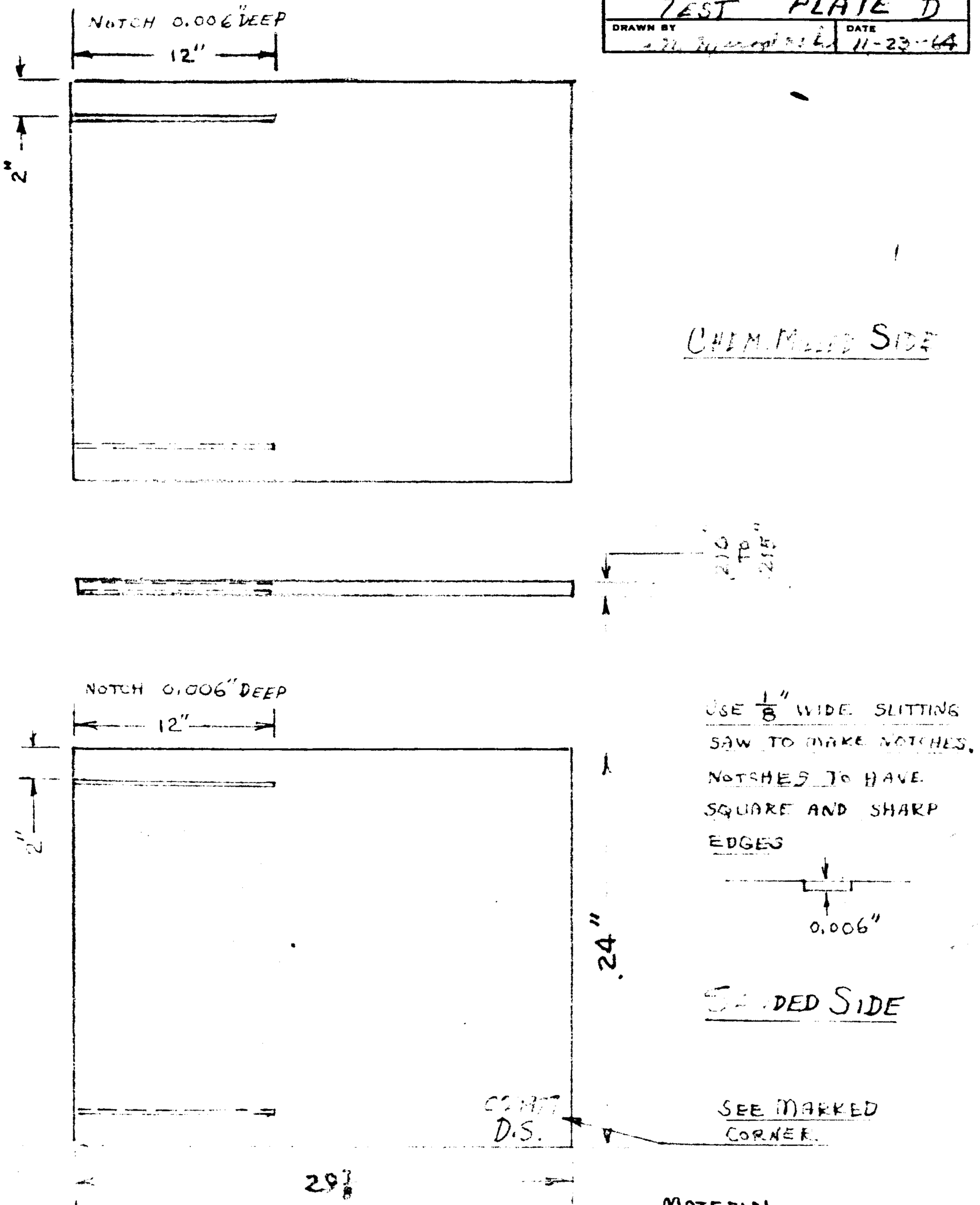
FORM 1.41 2079

SPERRY PRODUCTS

DIVISION OF AUTOMATION INDUSTRIES, INC.

SKETCH SHEET

SKETCH NO. 3	FILE REF. C-2998-T
CUSTOMER NASA	
ADDRESS	
TITLE TEST PLATE "D"	
DRAWN BY [illegible]	DATE 11-23-64



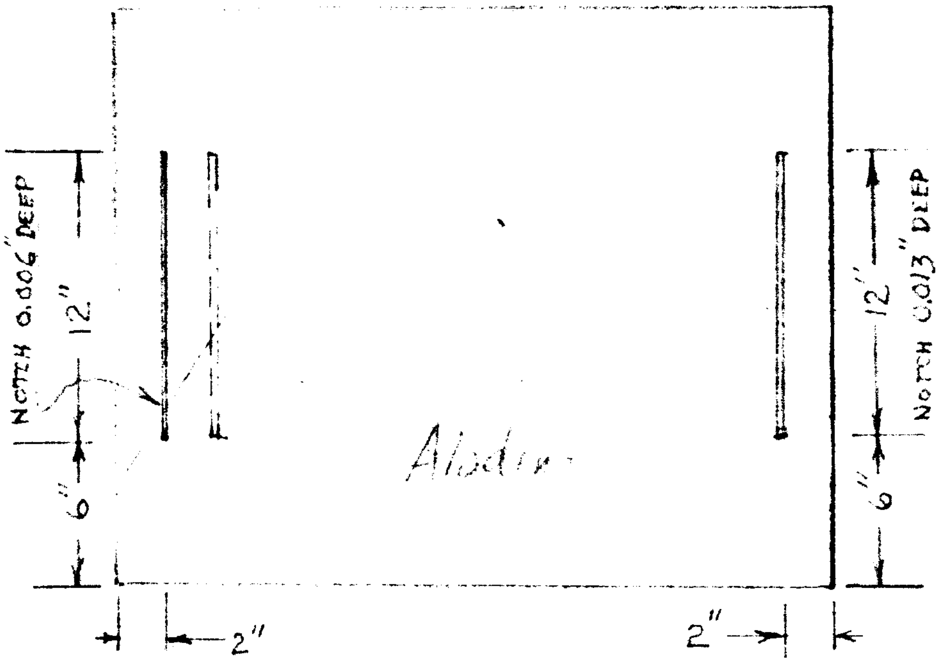
MATERIAL

ALUMINUM 2219-T37

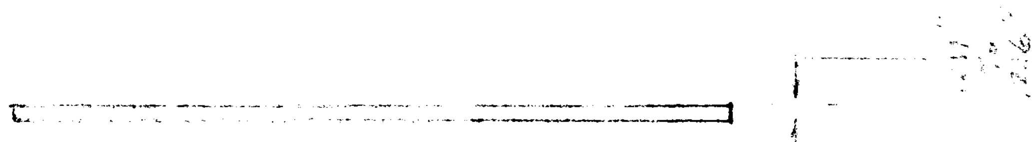
FORM 1.41

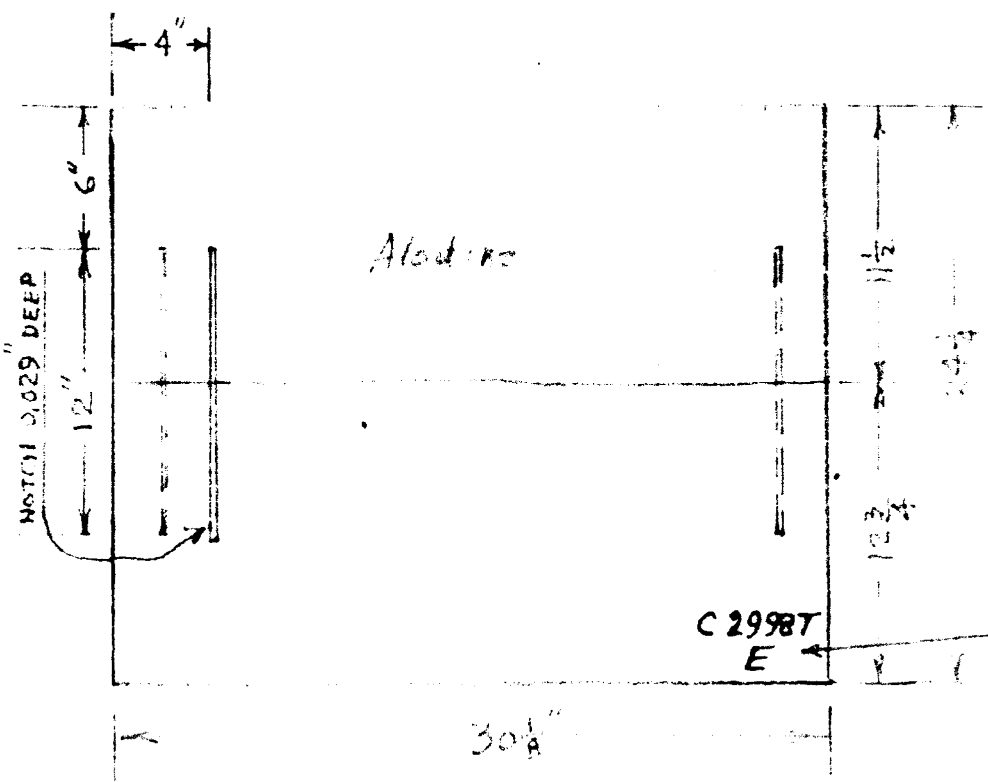
SPERRY PRODUCTS
DIVISION OF AUTOMATION INDUSTRIES, INC.
SKETCH SHEET

SKETCH NO. 4	FILE REF. C-2998-T
CUSTOMER NASA	
ADDRESS	
TITLE TEST PLATE "E"	
DRAWN BY G M Dimarolech	DATE 11-23-64

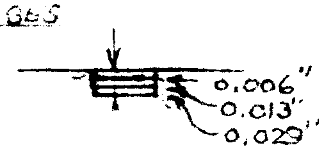


MATERIAL
ALUMINUM 2219-T87
FINISH
MILL & SAND OVERALL;
ALODINE ½ AREA





USE ⅛" WIDE SLITTING SAW TO MAKE NOTCHES
NOTCHES TO HAVE SQUARE & SHARP EDGES



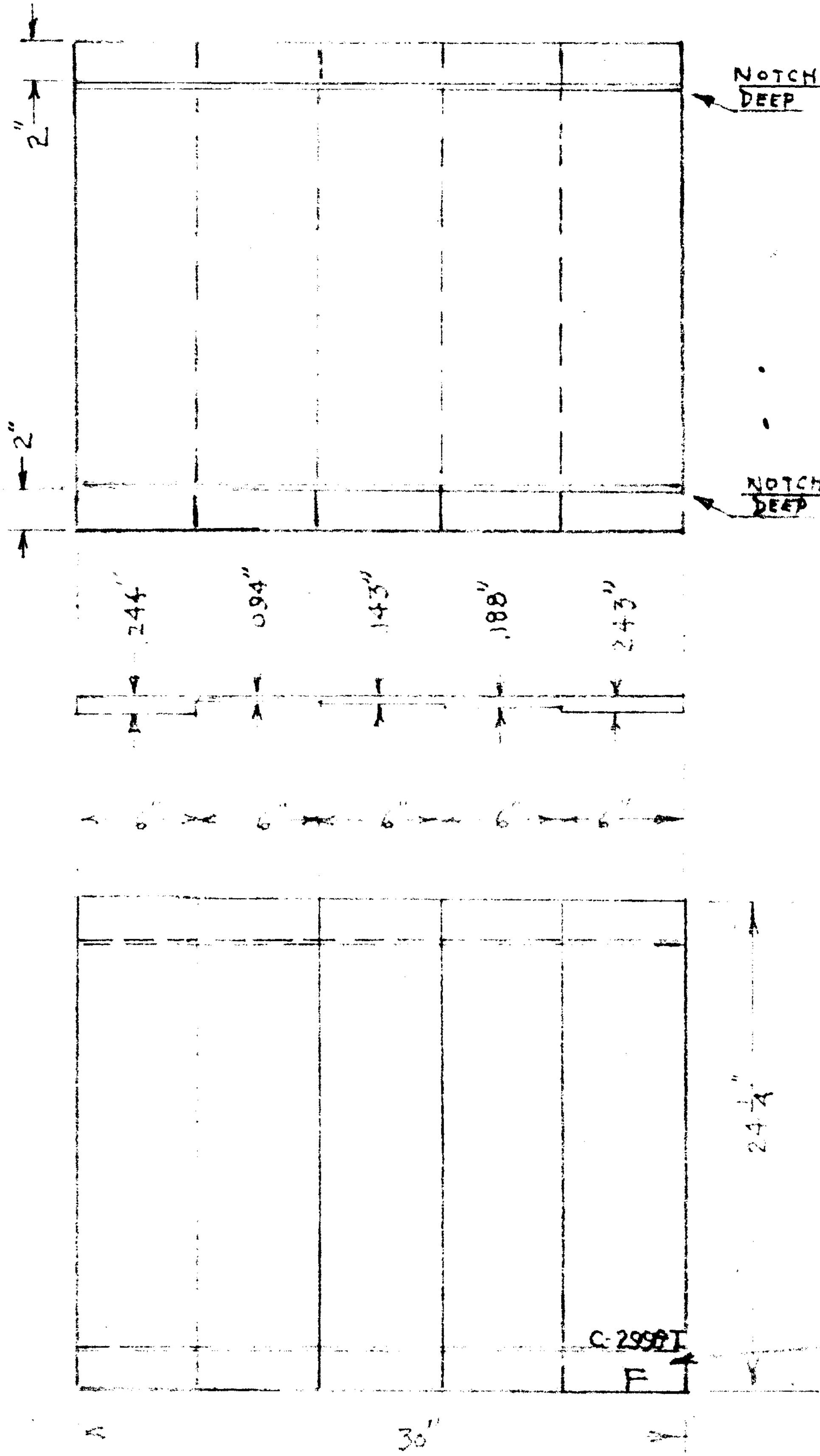
SEE MARKED CORNER

FORM 1.41

9181

SPERRY PRODUCTS
DIVISION OF AUTOMATION INDUSTRIES, INC.
SKETCH SHEET

SKETCH NO. 5	FILE REF. C-2998-T
CUSTOMER NASA	
ADDRESS	
TITLE TEST PLATE F	
DRAWN BY G.M. [illegible]	DATE 11-23-64



USE 1/8" WIDE SLITTING SAW TO MAKE NOTCHES
NOTCHES TO HAVE SQUARE & SHARP EDGES

0.006"
0.013"

MATERIAL
ALUMINUM 2219-T87
FINISH
MILL & SAND

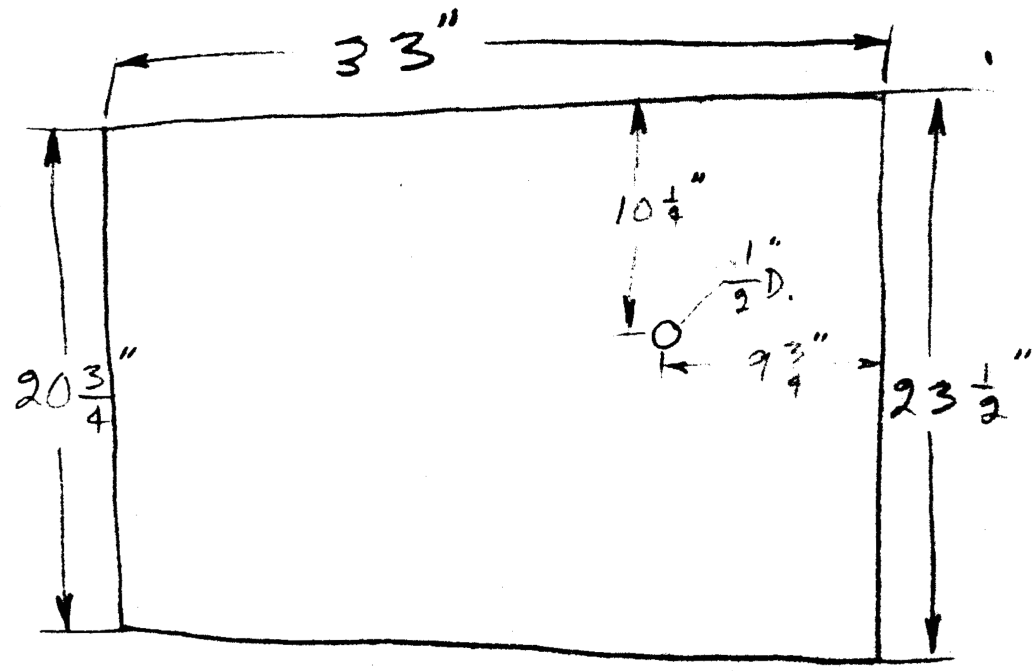
SEE MARKED CORNER

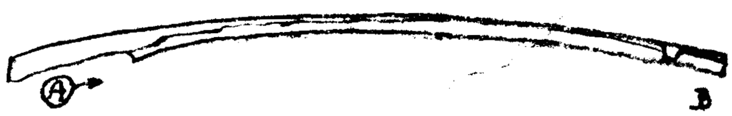
FORM 1.41

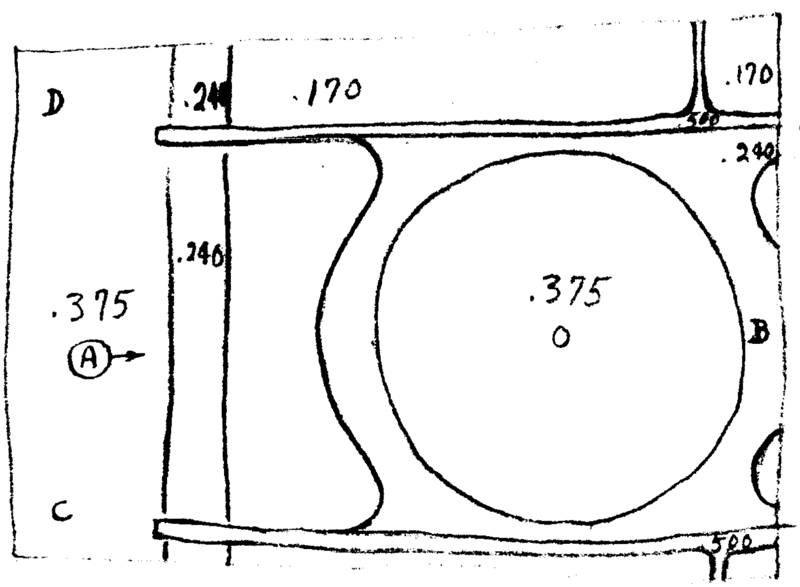
9181

SPERRY PRODUCTS
DIVISION OF AUTOMATION INDUSTRIES, INC.
SKETCH SHEET

SKETCH NO. 6	FILE REF. C 2998T
CUSTOMER NASA	
ADDRESS	
TITLE SURFACE WAVE PLATE G	
DRAWN BY WCMcG	DATE 8-31-69





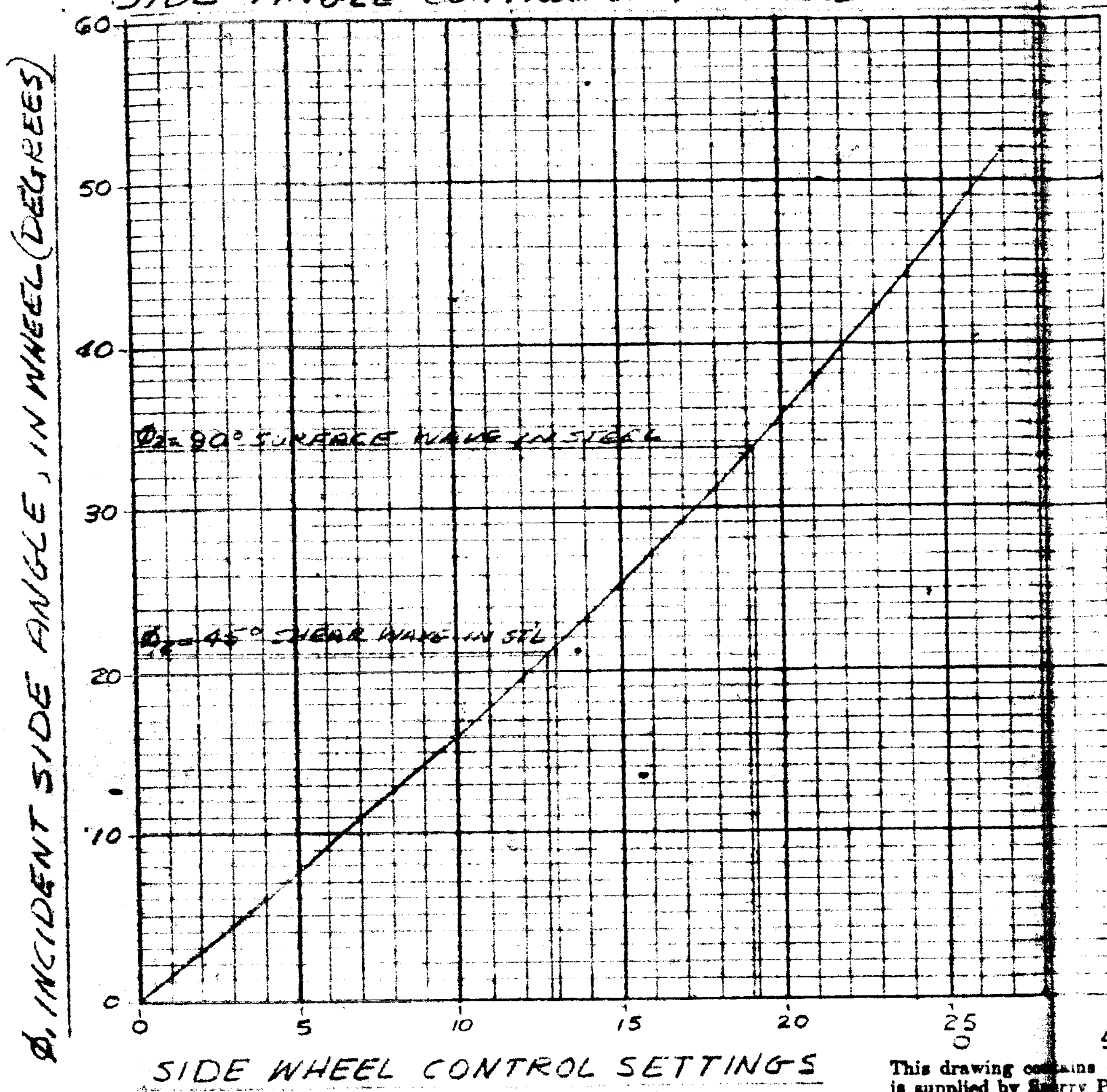


MATERIAL
ALUMINUM 2219-T87
FINISH -- "FINAL"

FORM 1.41

14734

SIDE ANGLE CONTROL OF VARIABLE ANGLE WHEEL



THIS WHEEL ALSO HAS FORWARD AND REVERSE 15° INCIDENT ANGLE ADJUSTMENT, THIS CALIBRATION CHART IS FOR 0° SETTING OF FORWARD-REVERSE ANGLE CONTROL. CANTED ANGLES ARE EASILY MEASURED BY METHOD INDICATED AT RIGHT (BELOW).

FOR REPRODUCIBLE CRYSTAL POSITIONS, TURN CONTROLS CLOCKWISE TO DESIRED POSITION

METHODS OF DETERMINING THE REFRACTED ANGLE ϕ_2

THEORETICAL APPROXIMATION

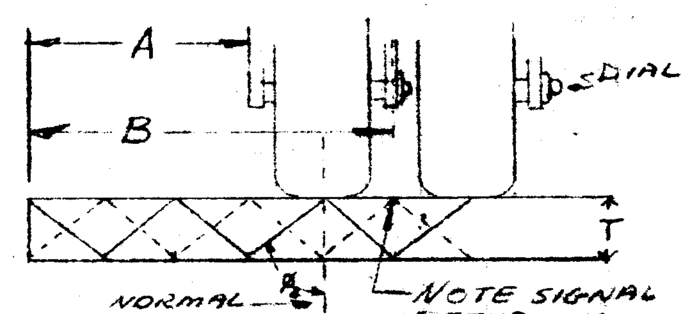
$SIN\ \phi_2 = \frac{V\ SIN\ \phi_1}{1.66}$ WHERE V = VELOCITY IN MATL BEING TESTED

$\phi_2 = ARCSIN\ \frac{V\ SIN\ \phi_1}{1.66}$ ϕ_1 = INCIDENT ANGLE

APPROXIMATE VELOCITIES $\times 10^5$ cm/SEC

	LONGITUDINAL	TRANSVERSE	SURFACE
STEEL	5.89	3.24	3.00
ALUM	6.30	3.15	2.95

ACTUAL MEASUREMENT



$TAN\ \phi_2 = \frac{B-A}{2T}$

$\phi_2 = ARCTAN\ \frac{B-A}{2T}$

ITEM NO.	DWG. OR PART NO.	NAME	QUAN REQ.

BILL OF MATERIAL

SCALE	50D340 REF. ASS'Y NO	SPERRY PRODUCTS DIVISION OF AUTOMATION INDUSTRIES, INC. DANBURY, CONNECTICUT, U.S.A.	
EXCEPT AS NOTED		SIDE ANGLE CONTROL CALIBRATION FOR VARIABLE ANGLE WHEEL	
DEC. ±		50B1274	
FRAC. ±	MAT. OR P. SPEC.	GC 4-3-64	MFG CHECK BY DATE
ANGLES ±		DRAWN BY DATE 4-6-64	
MACH. ✓	FINISH	CHECKED BY DATE 4-6-64	50B1274
		APPROVED BY DATE	

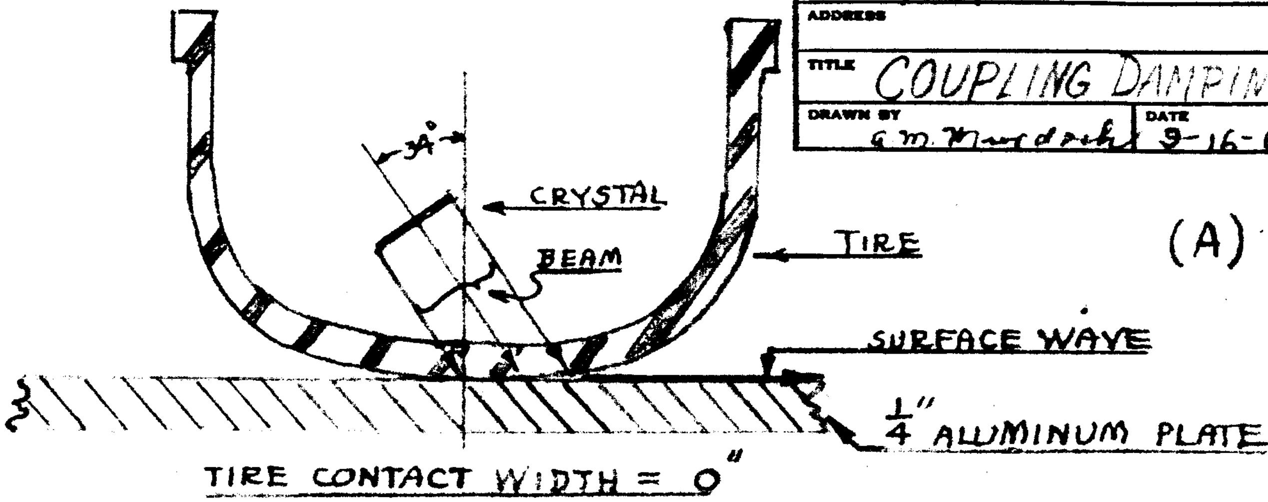
CHK.	DATE	E.C.N. NO.	LTR.	ENG. REF.	TIMES USED

FIG. 7

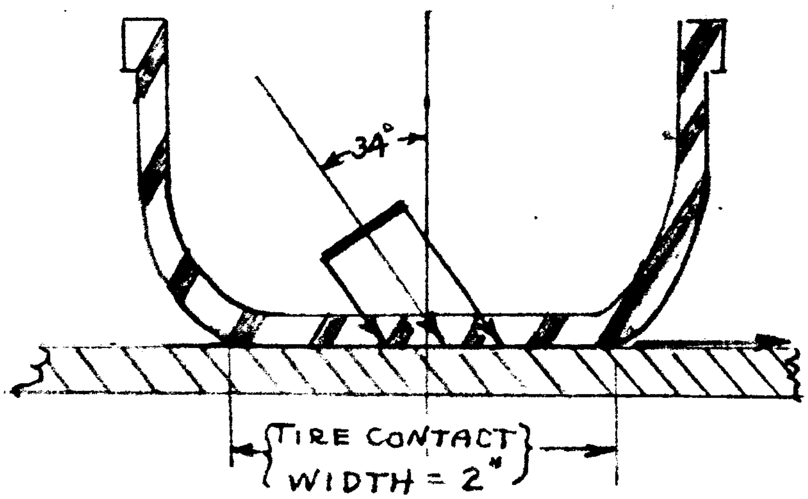
NASA C-2998-T

SPERRY PRODUCTS
DIVISION OF AUTOMATION INDUSTRIES, INC.
SKETCH SHEET

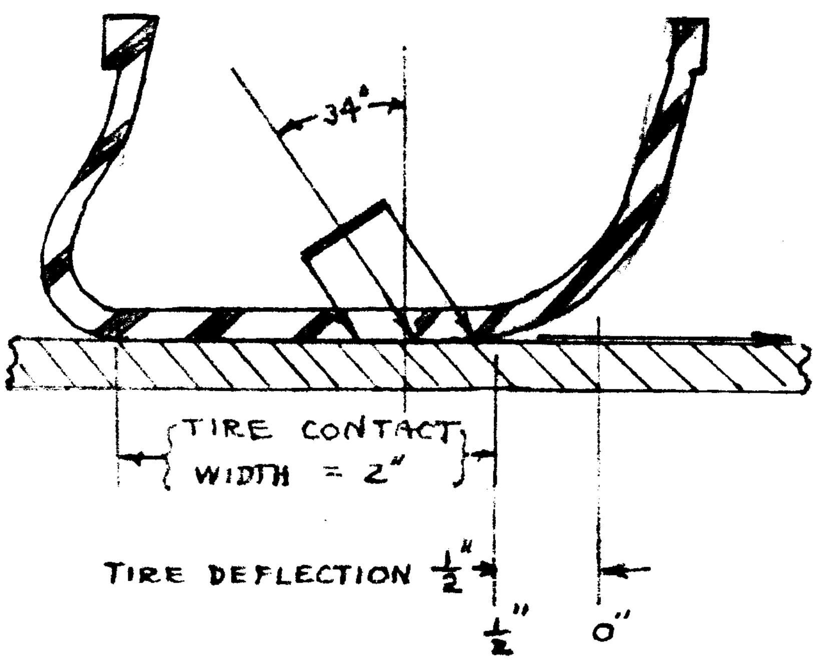
SKETCH NO. 8	FILE REF. C2998T
CUSTOMER NASA	
ADDRESS	
TITLE COUPLING DAMPING	
DRAWN BY G.M. Murdoch	DATE 9-16-64



(A)



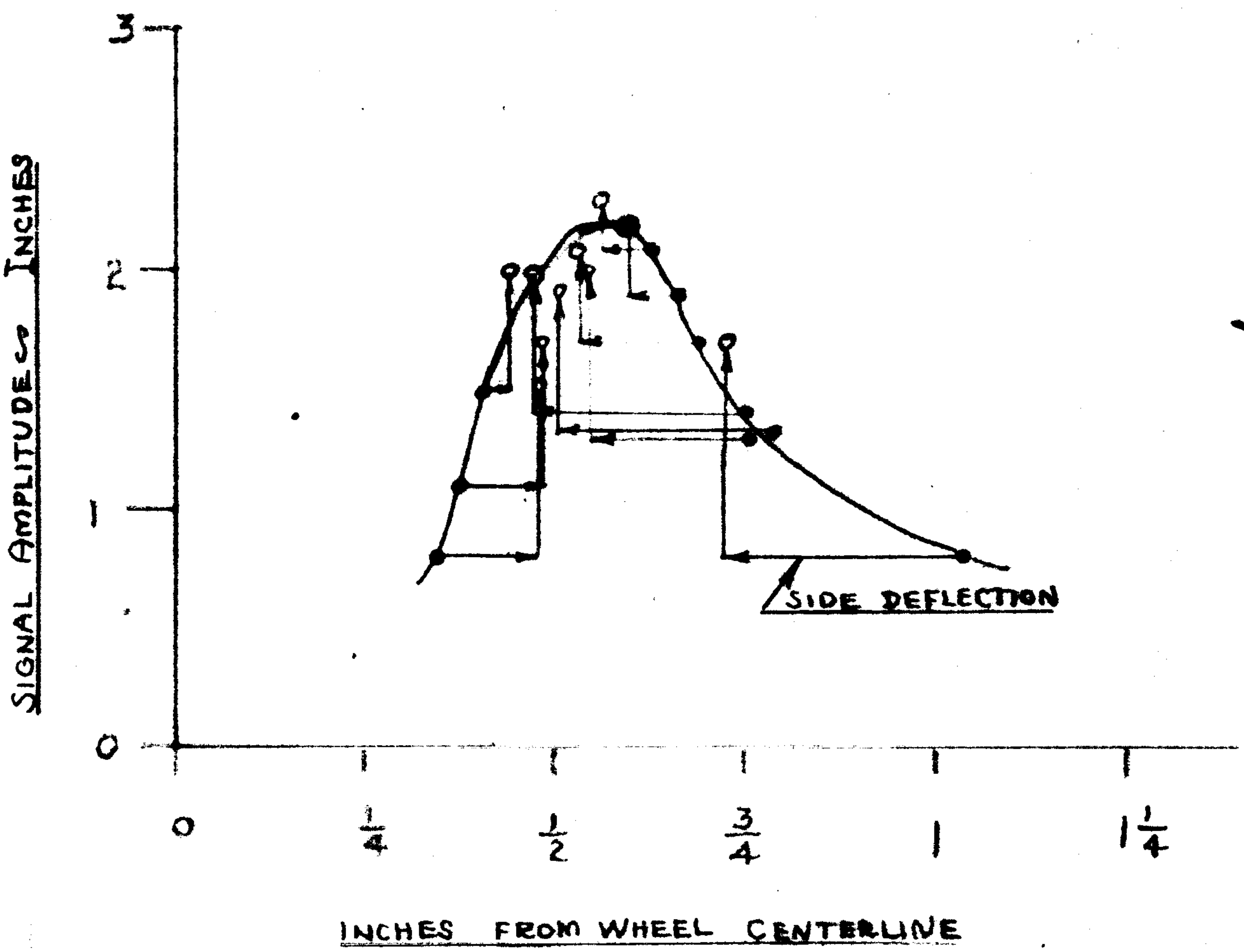
(B)



(C)

SPERRY PRODUCTS
DIVISION OF AUTOMATION INDUSTRIES, INC.
SKETCH SHEET

SKETCH NO. 9	FILE REF. C-2998-T
CUSTOMER NASA	
ADDRESS	
TITLE WIDTH DEFLECTION STUDY	
DRAWN BY G.M. Murdock	DATE 9-29-64

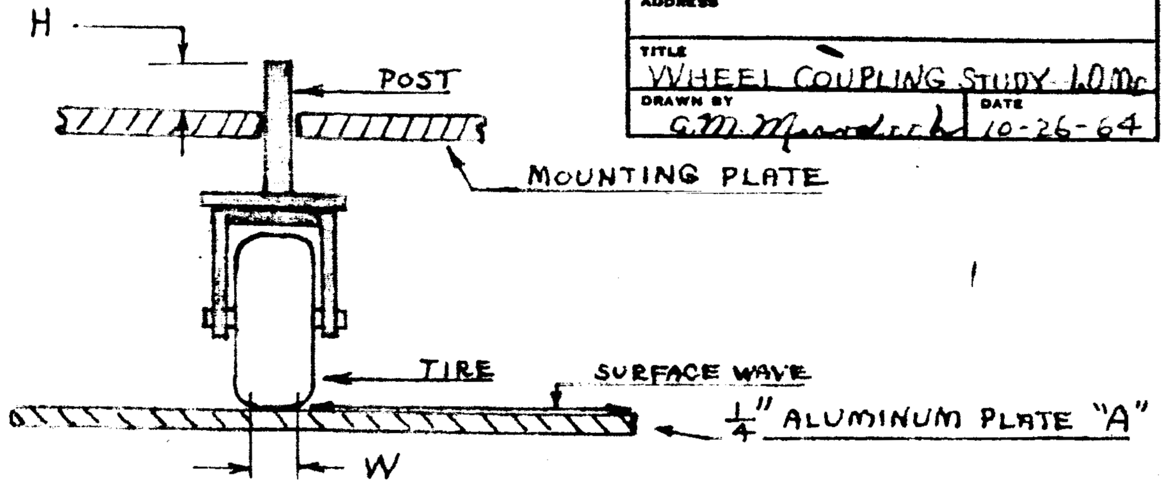


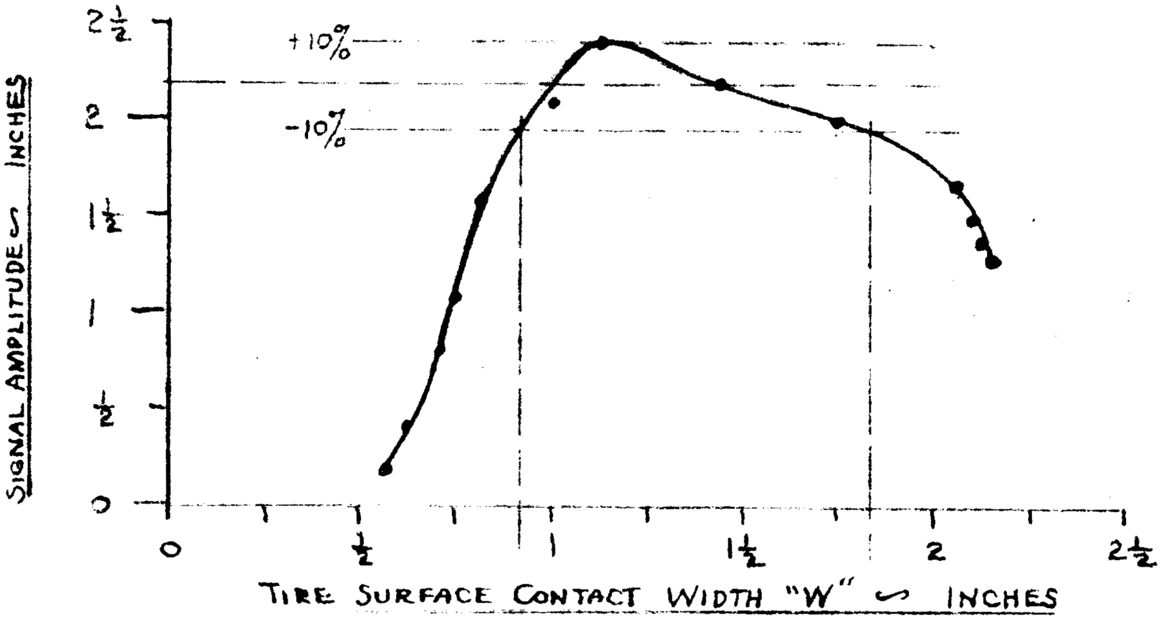
TIRE SURFACE CONTACT FOR DIFFERENT TIRE DIMENSIONS SHOWING EFFECT OF SIDE DEFLECTION OF TIRE ON SURFACE WAVE AMPLITUDE.

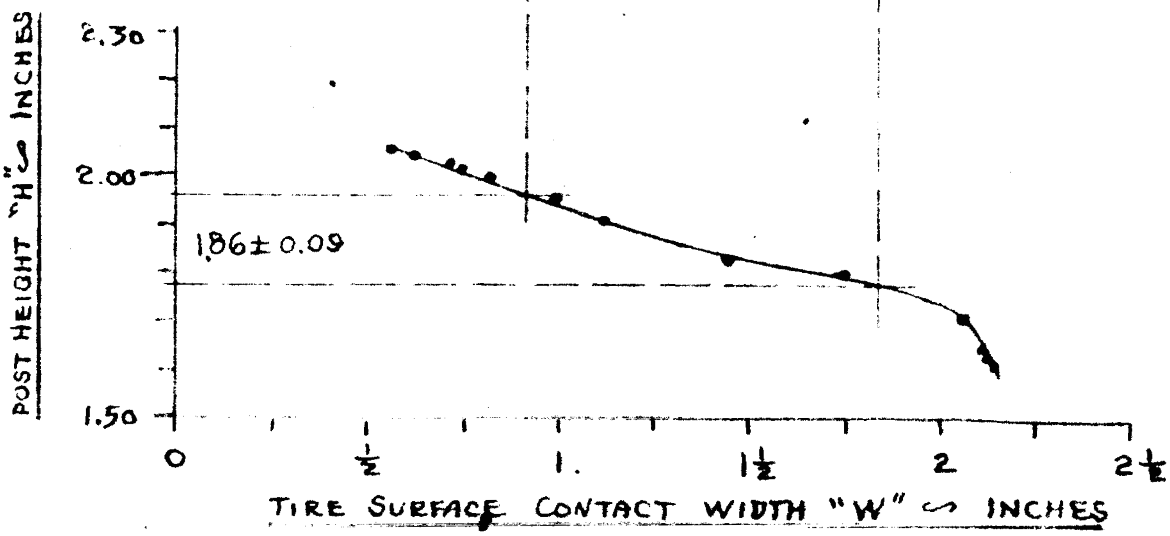
- ● SIGNAL AMPLITUDE WITH NO SIDE DEFLECTION OF TIRE
- ○ SIGNAL AMPLITUDE WHEN PEAKED BY DEFLECTING TIRE TOWARD A SIDE

SPERRY PRODUCTS
DIVISION OF AUTOMATION INDUSTRIES, INC.
SKETCH SHEET

SKETCH NO. 10	FILE REF. C-2998-T
CUSTOMER NASA	
ADDRESS	
TITLE WHEEL COUPLING STUDY 1.0 Mc	
DRAWN BY G.M. Murdock	DATE 10-26-64





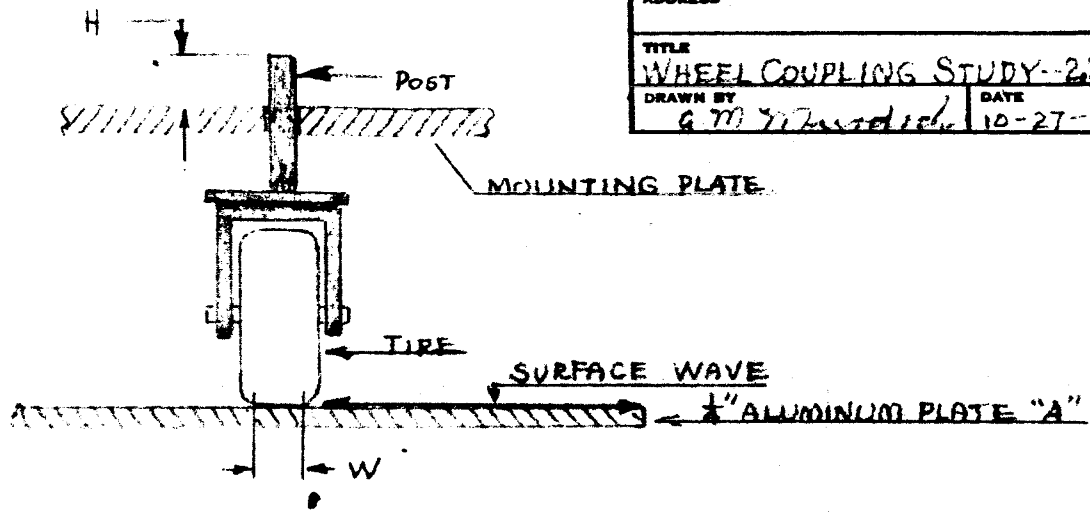


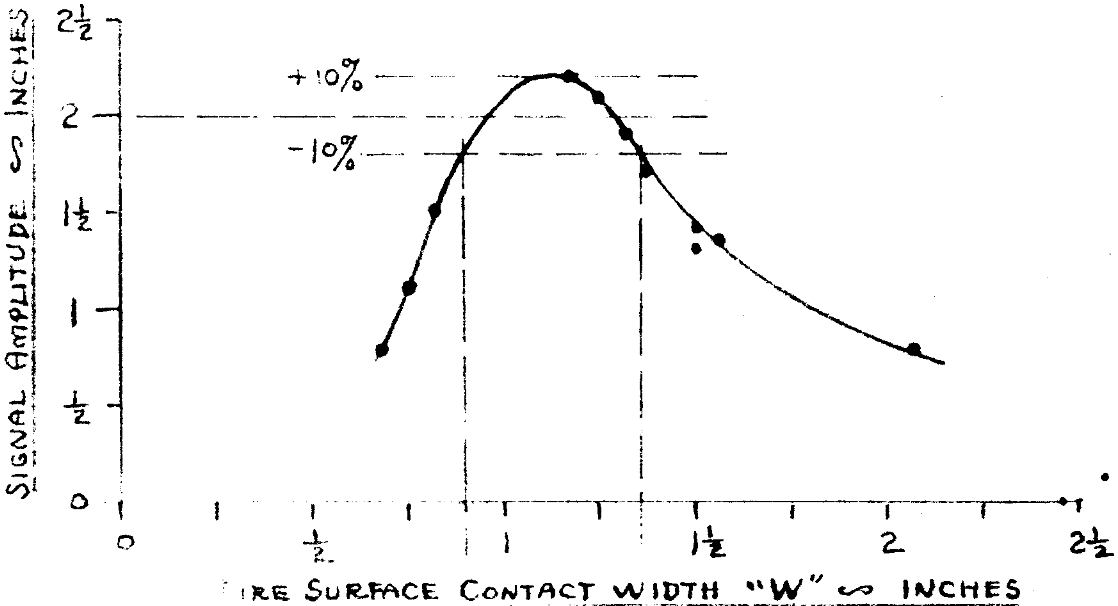
SEARCH UNIT – TYPE SOB; 1.0 Mc./ 1/2" x 1"
STYLE 50D403; SERIAL T-1719

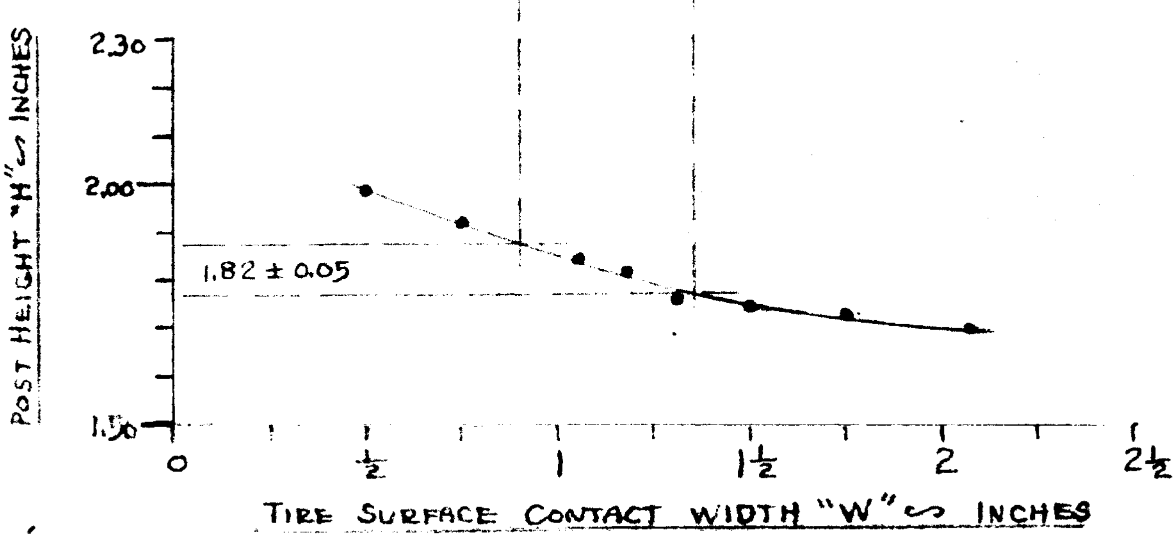
FORM 1.41

SPERRY PRODUCTS
DIVISION OF AUTOMATION INDUSTRIES, INC.
SKETCH SHEET

SKETCH NO. 11	FILE REF. C-2998-T
CUSTOMER NASA	
ADDRESS	
TITLE WHEEL COUPLING STUDY--2.25Mc	
DRAWN BY G M Murdick	DATE 10-27-64



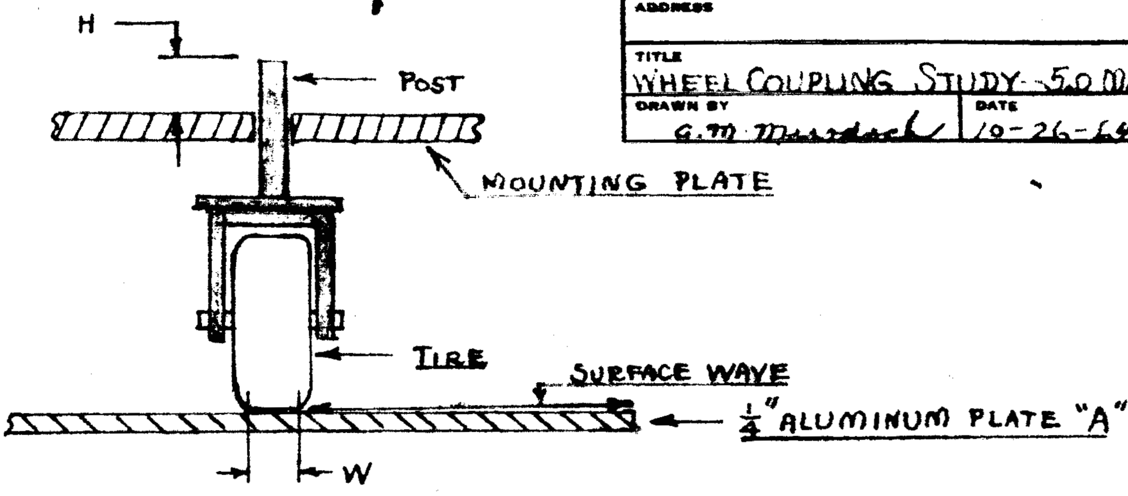


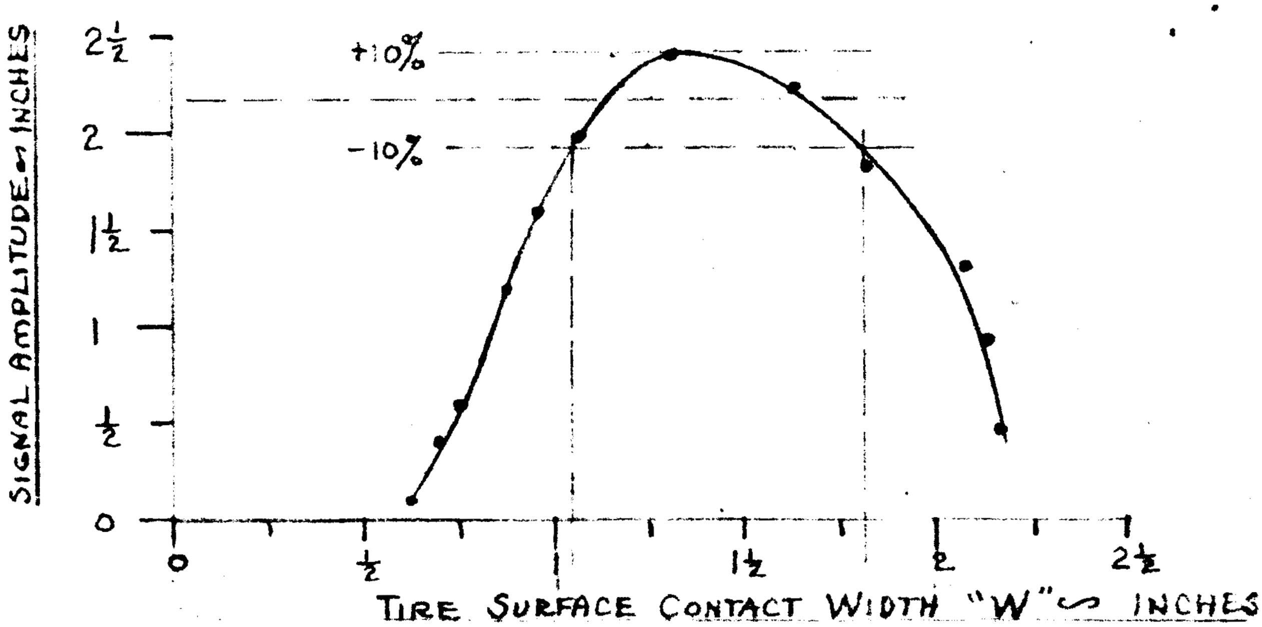


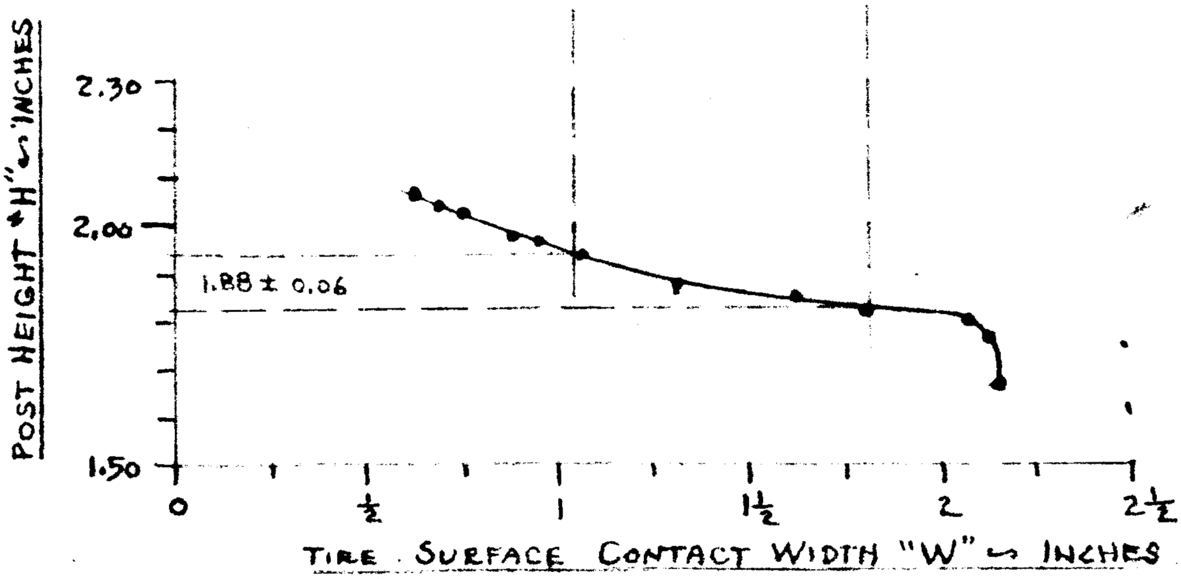
SEARCH UNIT TYPE SOB ; 2.25 mc/½" x 1"
STYLE 50D340 ; SERIAL T-1723

SPERRY PRODUCTS
DIVISION OF AUTOMATION INDUSTRIES, INC.
SKETCH SHEET

SKETCH NO. 12	FILE REF. C-2998-T
CUSTOMER NASA	
ADDRESS	
TITLE WHEEL COUPLING STUDY - 5.0 Mc	
DRAWN BY G.M. Murdock	DATE 10-26-64



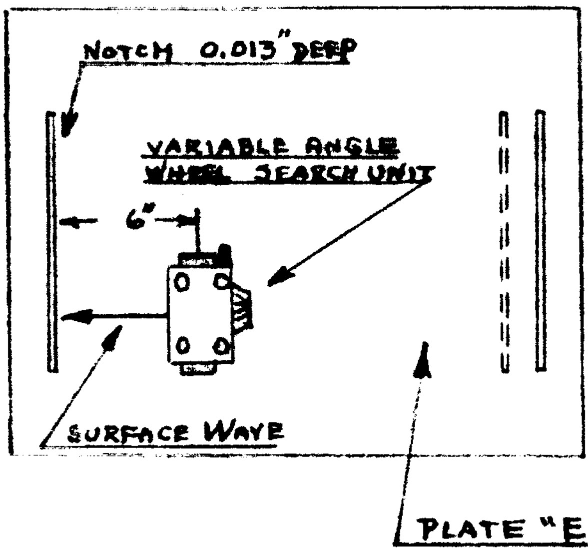




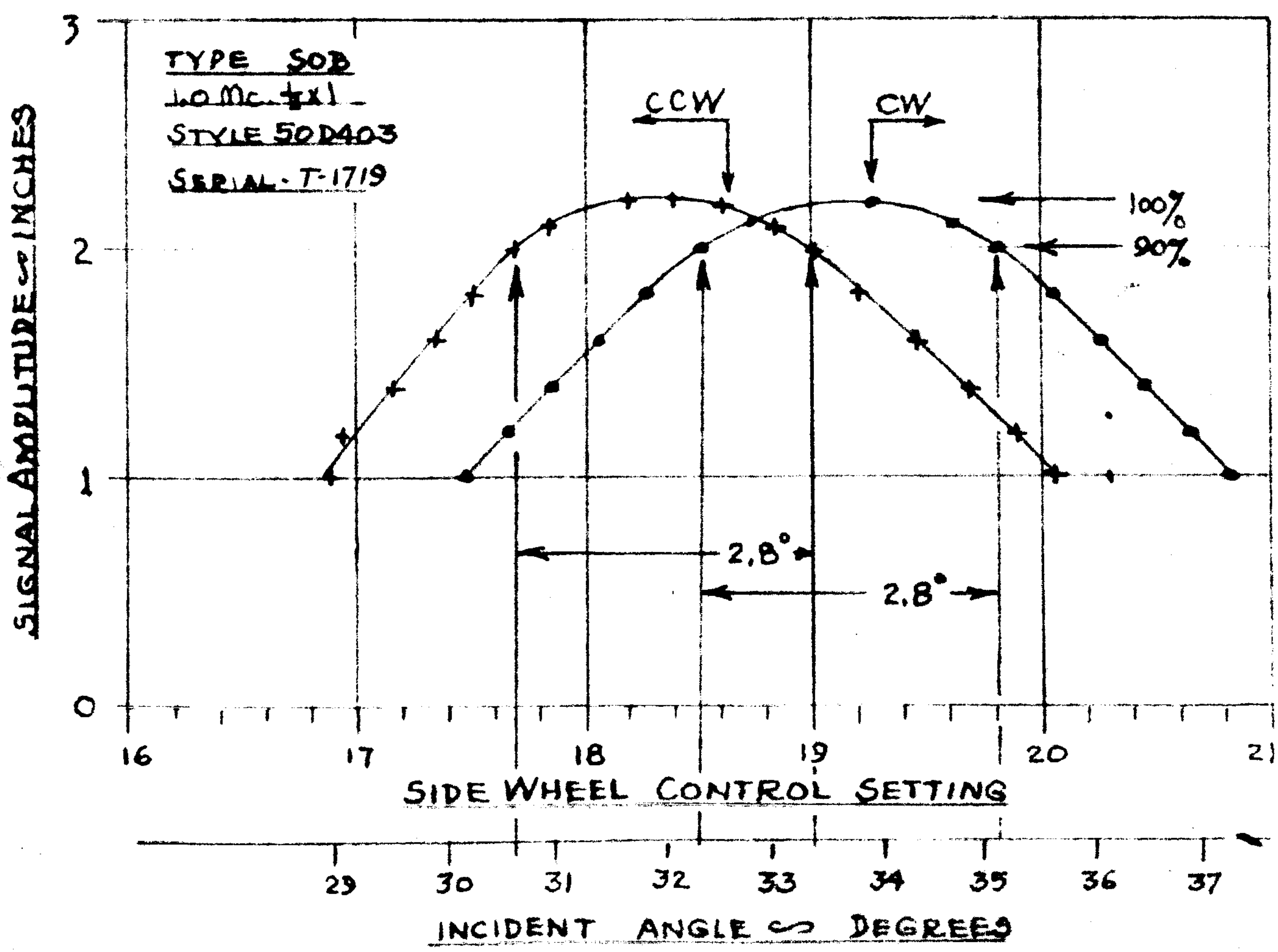
SEARCH UNIT - - TYPE SOB; 5.0Mc/½"x1" STYLE 50D404
SERIAL - - T-1720

SPERRY PRODUCTS
DIVISION OF AUTOMATION INDUSTRIES, INC.
SKETCH SHEET

SKETCH NO. 13	FILE REF. C-2998-T
CUSTOMER NASA	
ADDRESS	
TITLE INCIDENT ANGLE STUDY	
DRAWN BY G.M. Murdock	DATE 2-23-65

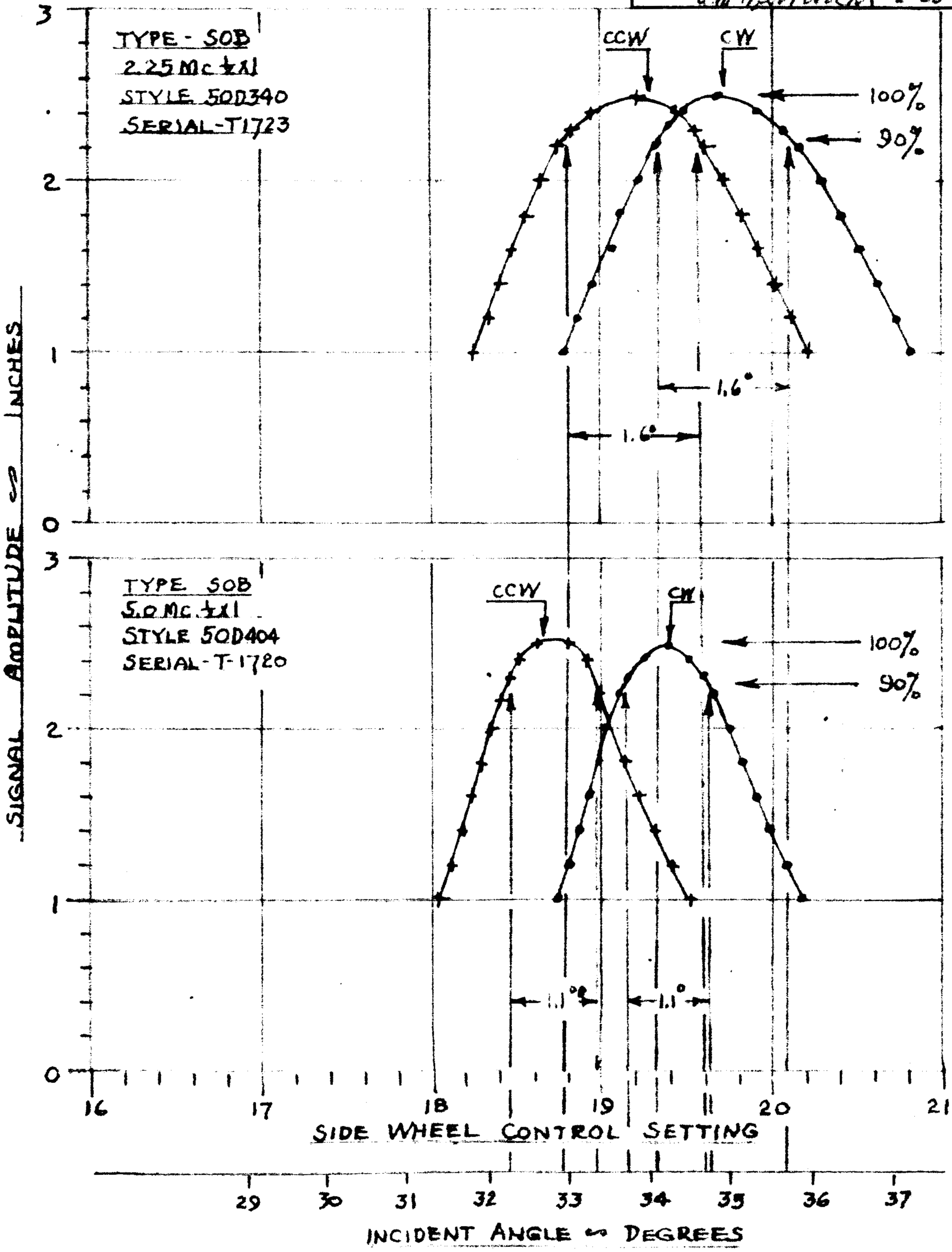


TEST PLATE --- "E"
SEARCH UNIT -- VARIABLE ANGLE WHEEL
WAVE TYPE -- SURFACE.
SIDE WHEEL CONTROL MOTION
● INCREASING (CW)
+ DECREASING (CCW)
REFLECTOSCOPE & SETTINGS
TYPE - UM; STYLE - 50B721
PULSE LENGTH -- MIN.
REJECT ----- OFF
SENSITIVITY - SET FOR PEAK SIGNAL AMPLITUDE NOT OVER 2.5"



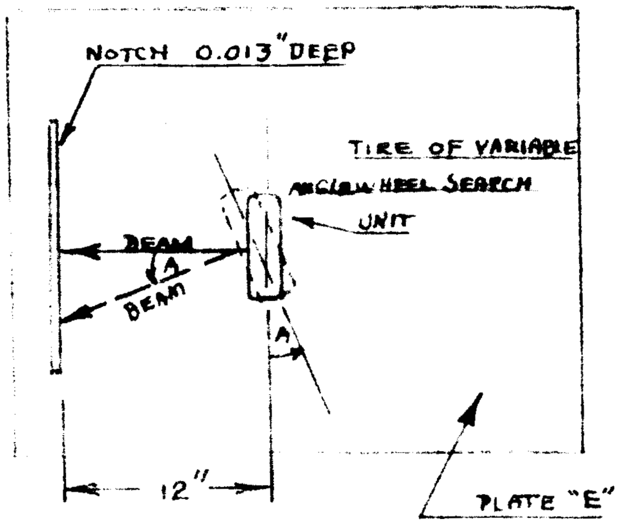
SPERRY PRODUCTS
DIVISION OF AUTOMATION INDUSTRIES, INC.
SKETCH SHEET

SKETCH NO. 14	FILE REF. C-2998-T
CUSTOMER NASA	
ADDRESS	
TITLE INCIDENT ANGLE STUDY	
DRAWN BY G.M. Murdoch	DATE 2-23-65

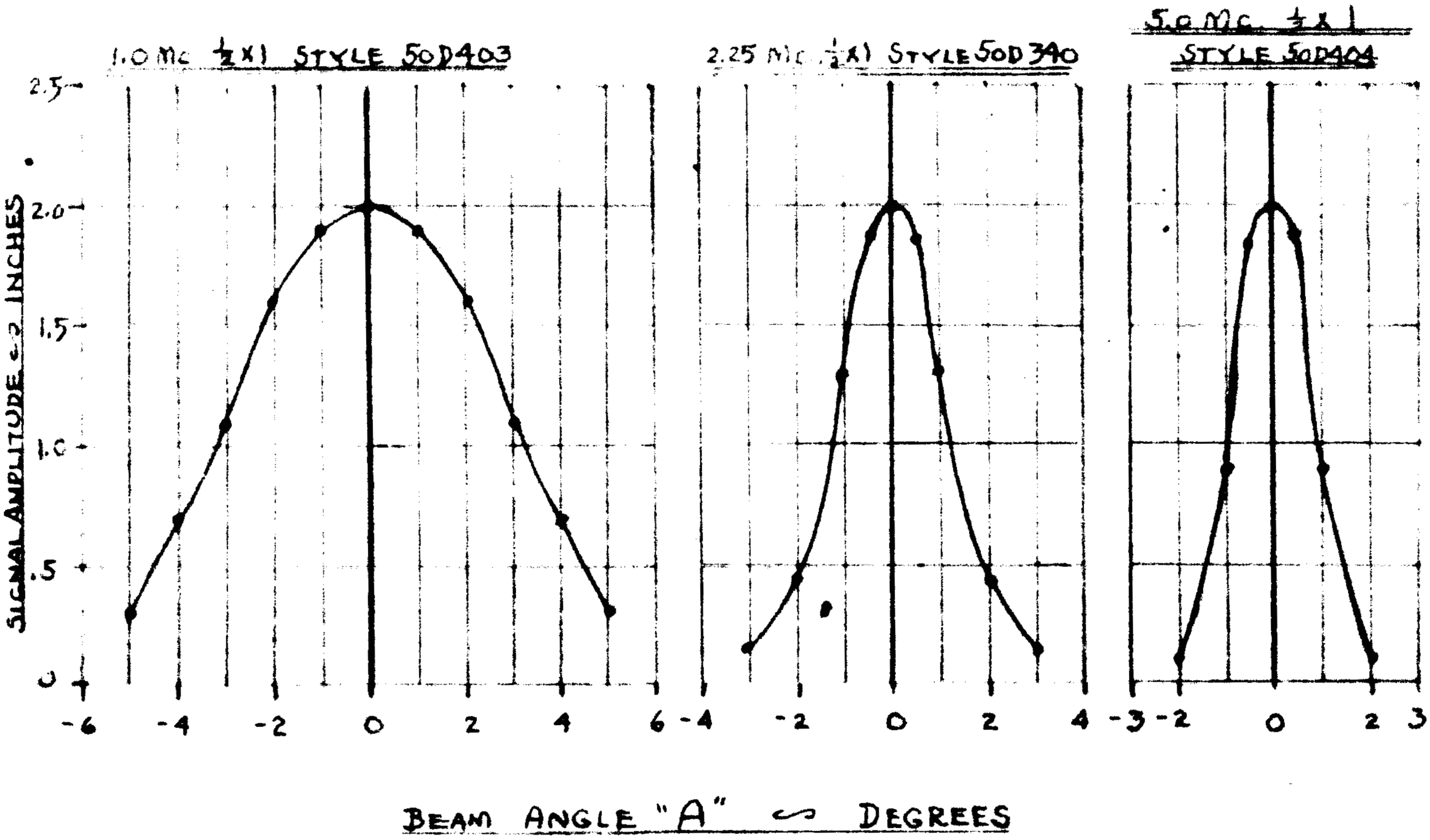


SPERRY PRODUCTS
DIVISION OF AUTOMATION INDUSTRIES, INC.
SKETCH SHEET

SKETCH NO. 15	FILE REF. C-2998-T
CUSTOMER NASA	
ADDRESS	
TITLE BEAM DIRECTION STUDY	
DRAWN BY [illegible]	DATE [illegible]



REFLECTOSCOPE -- UM-50B721 (5N)
TEST PLATE ----"E"
SEARCH UNITS (3) VARIABLE ANGLE WHEEL, TYPE 50B
REFLECTOSCOPE SETTINGS
PULSE LENGTH --MINIMUM REJECT --OFF
SENSITIVITY SET MAXIMUM REFLECTION FROM NOTCH TO 2 INCHES
WHEEL SEARCH UNIT CONTROLS
FORWARD/BACKWARD --- 0°
SIDE ANGLE -- SET FOR MAXIMUM AMPLITUDE SURFACE WAVE



SPERRY PRODUCTS
DIVISION OF AUTOMATION INDUSTRIES, INC.
SKETCH SHEET

SKETCH NO. 16	FILE REF. C-2998T
CUSTOMER NASA	
ADDRESS	
TITLE S.U. CABLE LENGTH STUDY	
DRAWN BY G.M. Murdock	DATE 3-12-65

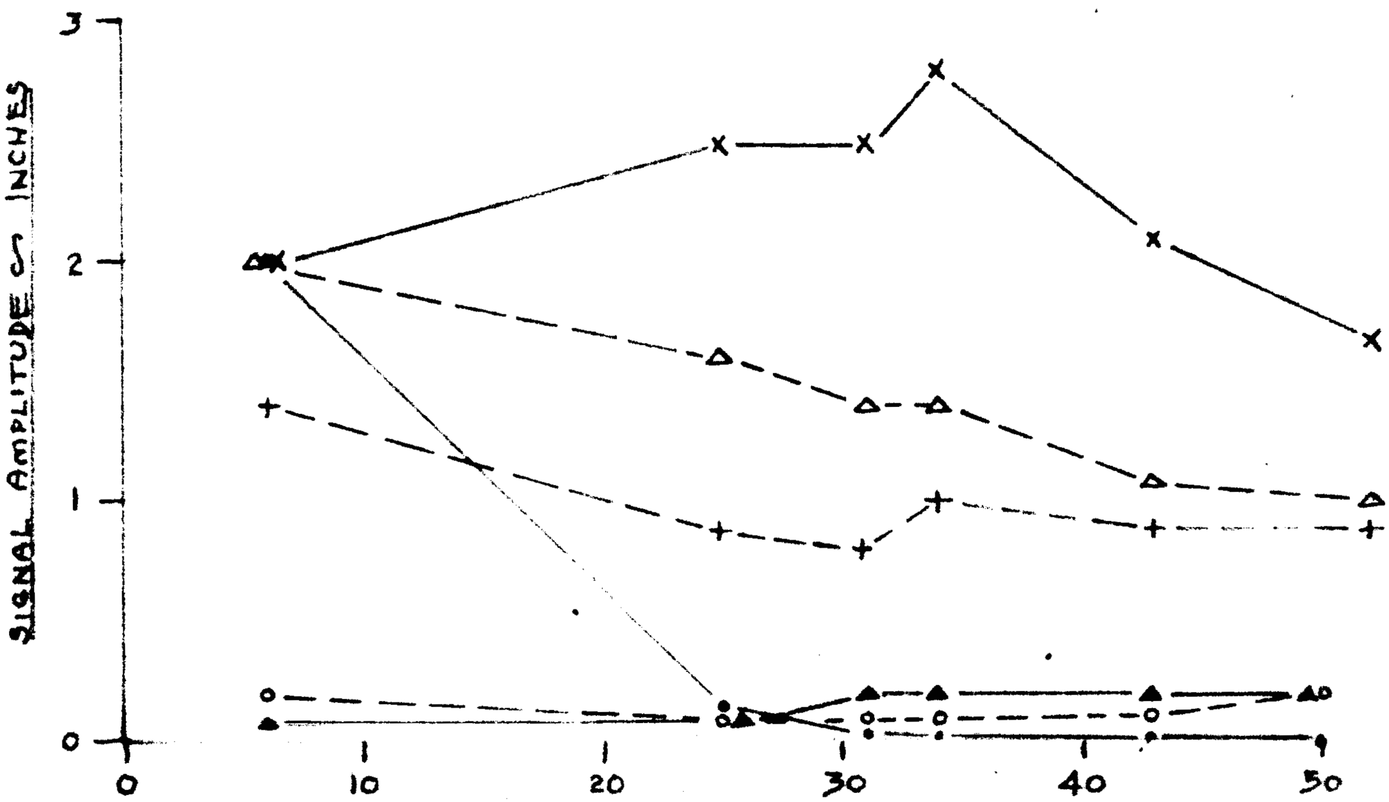
REFLECTOSCOPE--UM - 50B721 (5N)

VARIABLE ANGLE WHEEL SEARCH UNITS---TYPE- 50B--SIZE ½x1

FREQ	STYLE	SERIAL
1.0 Mc.	50D403	T-1719
2.25 Mc.	50D340	T-1723
5.0 Mc.	50D404	T-1720

CABLE TYPE---AMPHENOL --RG 62 B/U

SIGNAL AMPLITUDE ~ CABLE LENGTH



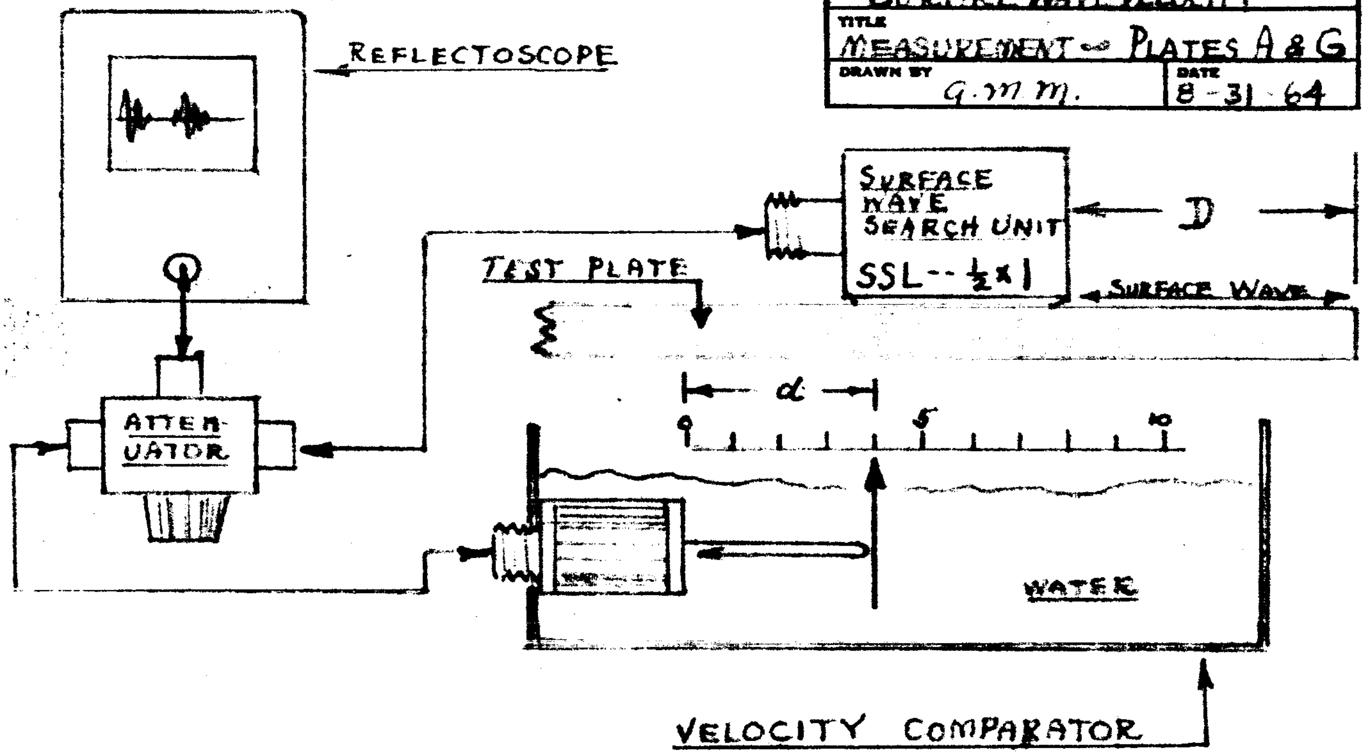
SYMBOL	FREQUENCY	TEST	REFLECTOSCOPE SETTINGS			
	MC.-WHEEL S.U.	JACK	SENSITIVITY	PULSE LENGTH	REJECT	FREQ.
——●——	1.0	T	1X1	MIN.	OFF	1.0
- - o - -	1.0	R	1X1	MIN.	OFF	1.0
——×——	2.25	T	1.2 x .1	MIN.	OFF	2.25
- - + - -	2.25	R	1.2 x .1	MIN.	OFF	2.25
——▲——	5.0	T	.5 x .1	MIN.	OFF	5.0
- - △ - -	5.0	R	.5 x .1	MIN.	OFF	5.0

FORM 1.41

19417

SPERRY PRODUCTS
DIVISION OF AUTOMATION INDUSTRIES, INC.
SKETCH SHEET

SKETCH NO. 17	FILE REF. C-2998-T
CUSTOMER NASA	
ADDRESS SURFACE WAVE VELOCITY	
TITLE MEASUREMENT - PLATES A & G	
DRAWN BY G.M.M.	DATE 8-31-64



$$V_R = \frac{(D_1 - D_2) \times V_{WATER}}{(d_1 - d_2)}$$

WHERE:

V_R = SURFACE WAVE VELOCITY, TEST PLATE
V_{WATER} = LONGITUDINAL VELOCITY, WATER
$(D_1 - D_2)$ = CHANGE IN POSITION, SURFACE WAVE SEARCH UNIT
$(d_1 - d_2)$ = CHANGE IN VELOCITY COMPARATOR SETTING

TEST PLATE	FREQUENCY MC.	SURFACE WAVE VELOCITY CM/SEC X10^5
"A" (FLAT)	5.0	2.90
	2.25	2.90
	1.0	2.97 ± 0.06 * (¼" THICK)
"G" (CURVED)	5.0	2.90
	2.25	2.90
	1.0	2.93 (⅜" THICK)

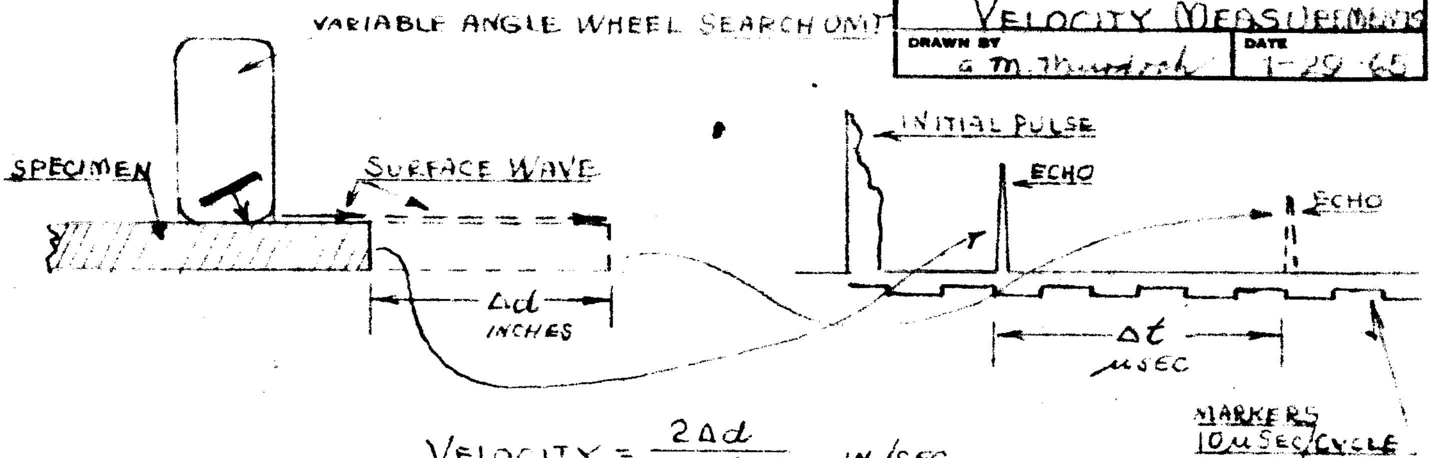
* INTERFERENCE FROM BOTTOM OF PLATE PRESENT

FORM 1.41

14734

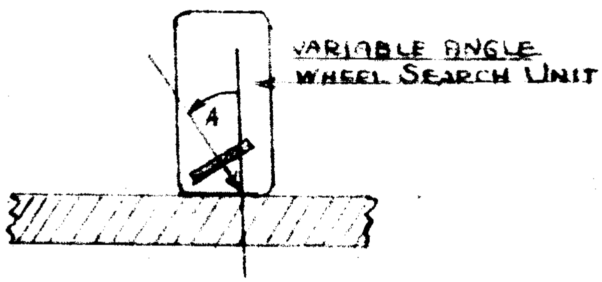
SPERRY PRODUCTS
DIVISION OF AUTOMATION INDUSTRIES, INC.
SKETCH SHEET

SKETCH NO.S 18, 19 AND 20	FILE REF. C-2998-T
CUSTOMER NASA	
ADDRESS	
TITLE VELOCITY MEASUREMENTS	
DRAWN BY G M Thurdock	DATE 1-29-65



$$\text{VELOCITY} = \frac{2\Delta d}{\Delta t} \quad \text{IN./SEC.}$$

FIG 18

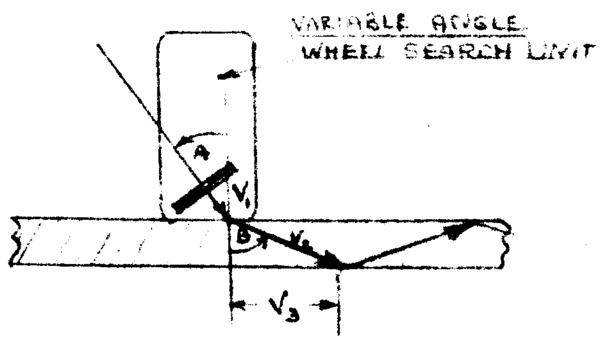


$$V_p = \frac{65500}{\sin A}$$

WHERE:

V_p = PHASE VELOCITY IN/SEC
A = INCIDENT ANGLE

FIG 19



$$\frac{\sin B}{\sin A} = \frac{V_2}{V_1}$$

$$V_3 = V_2 \sin B$$

$$\sin B = \frac{V_2 \sin A}{V_1}$$

$$V_3 = \frac{V_2^2 \sin A}{V_1}$$

WHEN V_1 = 65,500 IN/SEC IN FLUID

V_2 = 248,000 IN/SEC LONGITUDINAL
OR
124,000 IN/SEC SHEAR
IN ALUMINUM

V_3 = VELOCITY ALONG PLATE, IN/SEC

V_3 = 940,000 SIN A } FOR LONGITUDINAL

OR

V_3 = 230,000 SIN A } FOR SHEAR

WHERE A = INCIDENT ANGLE
$< 15.3°$ FOR LONGITUDINAL
$< 31.8°$ FOR SHEAR

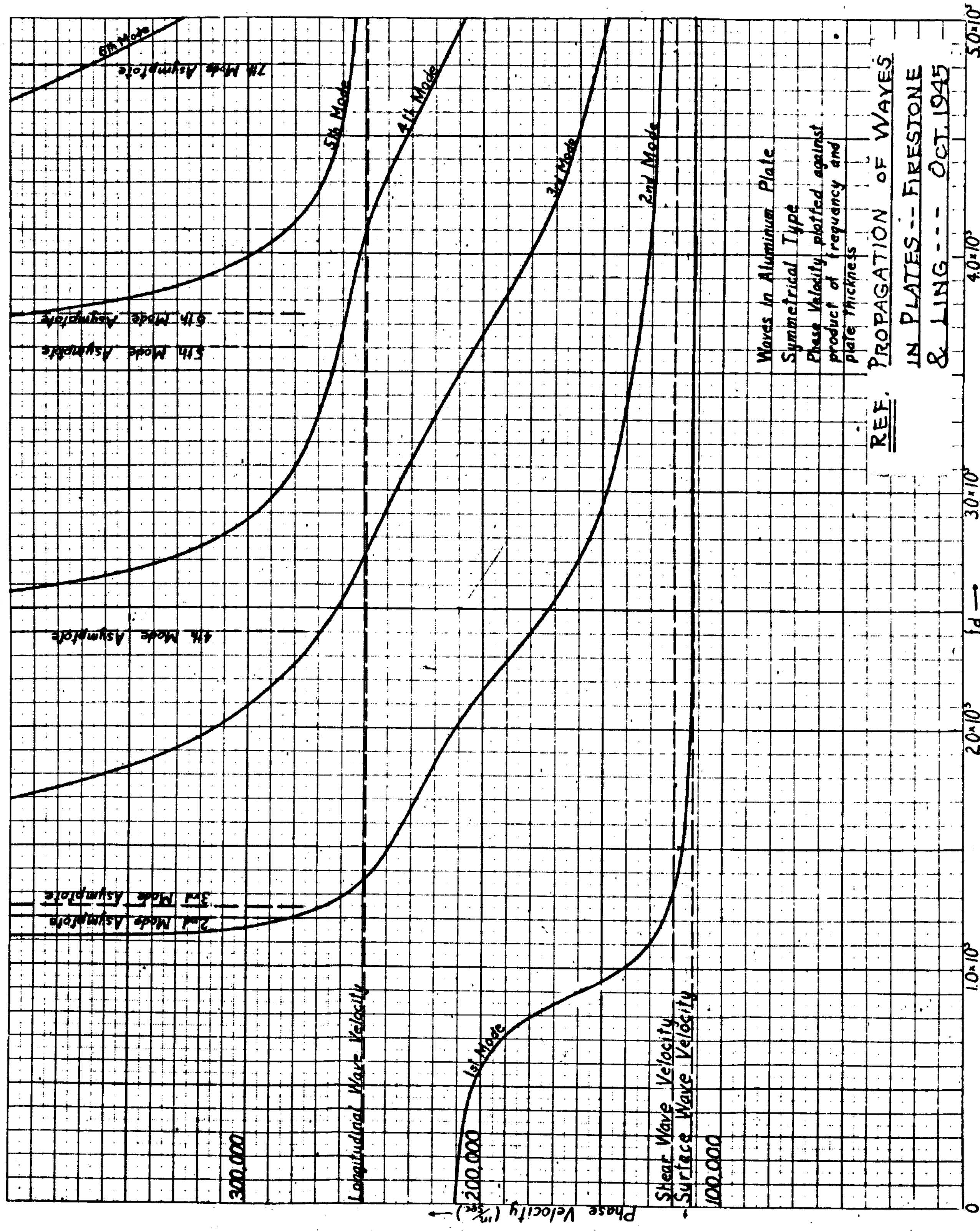
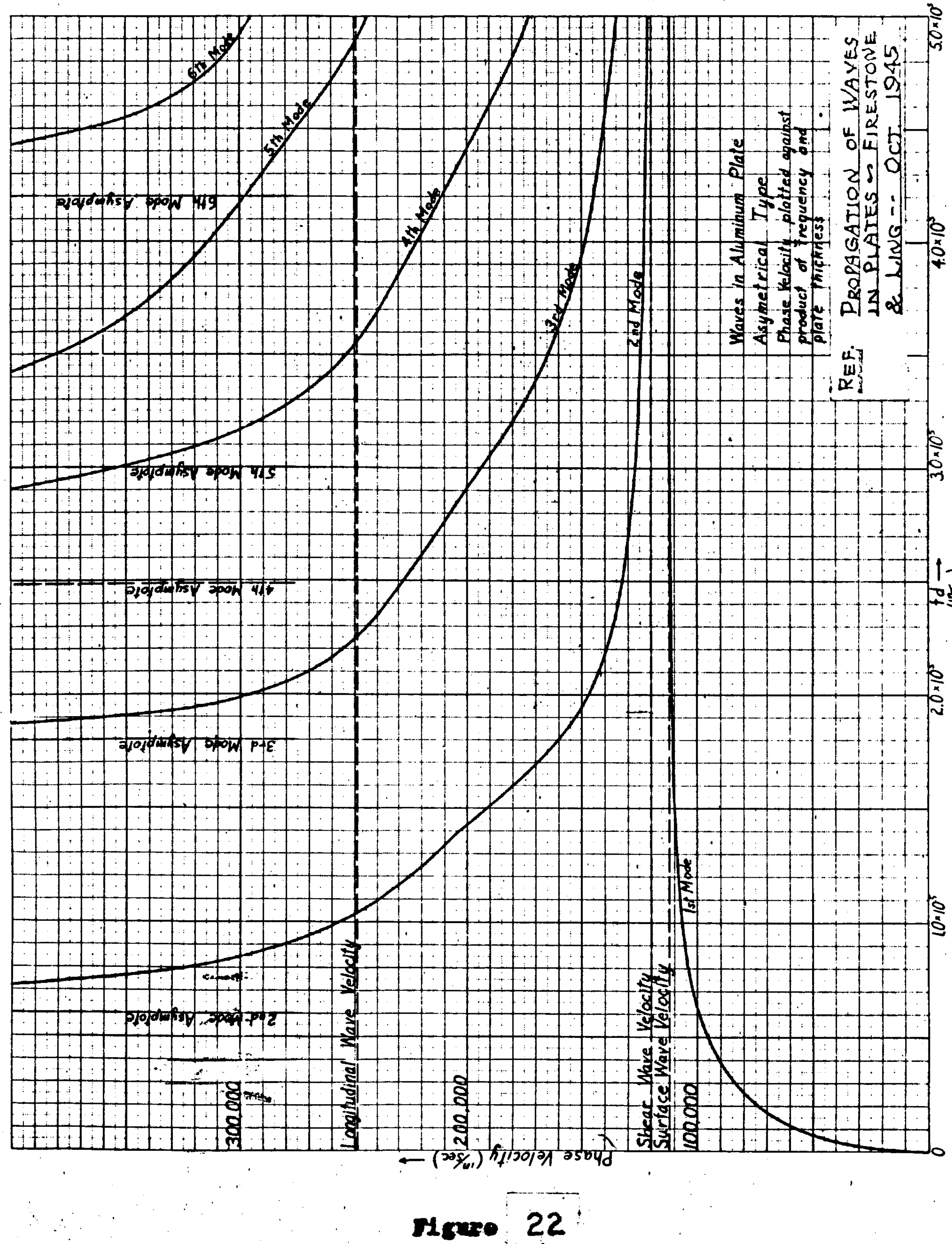

Waves In Aluminum Plate
Symmetrical Type
Phase Velocity plotted against product of frequency and plate thickness
REF. PROPAGATION OF WAVES IN PLATES -- FIRESTONE & LING --- OCT. 1945
1st Mode
2nd Mode
3rd Mode
4th Mode
5th Mode
6th Mode
2nd Mode Asymptote
3rd Mode Asymptote
4th Mode Asymptote
5th Mode Asymptote
6th Mode Asymptote
7th Mode Asymptote
Longitudinal Wave Velocity
Shear Wave Velocity
Surface Wave Velocity
300,000
200,000
100,000
Phase Velocity (in/sec)
0
1.0×10⁵
2.0×10⁵
3.0×10⁵
4.0×10⁵
5.0×10⁵
fd (in/sec)

Figure 21



Waves in Aluminum Plate
Asymetrical Type
Phase Velocity plotted against product of frequency and plate thickness
REF. PROPAGATION OF WAVES IN PLATES — FIRESTONE & LING -- OCT. 1945
6th Mode
5th Mode
4th Mode
3rd Mode
2nd Mode
1st Mode
6th Mode Asymptote
5th Mode Asymptote
4th Mode Asymptote
3rd Mode Asymptote
2nd Mode Asymptote
Longitudinal Wave Velocity
Shear Wave Velocity
Surface Wave Velocity
300,000
200,000
100,000
Phase Velocity ("/sec) →
0
1.0×10⁵
2.0×10⁵
3.0×10⁵
4.0×10⁵
5.0×10⁵
fd ("/sec) →

Figure 22

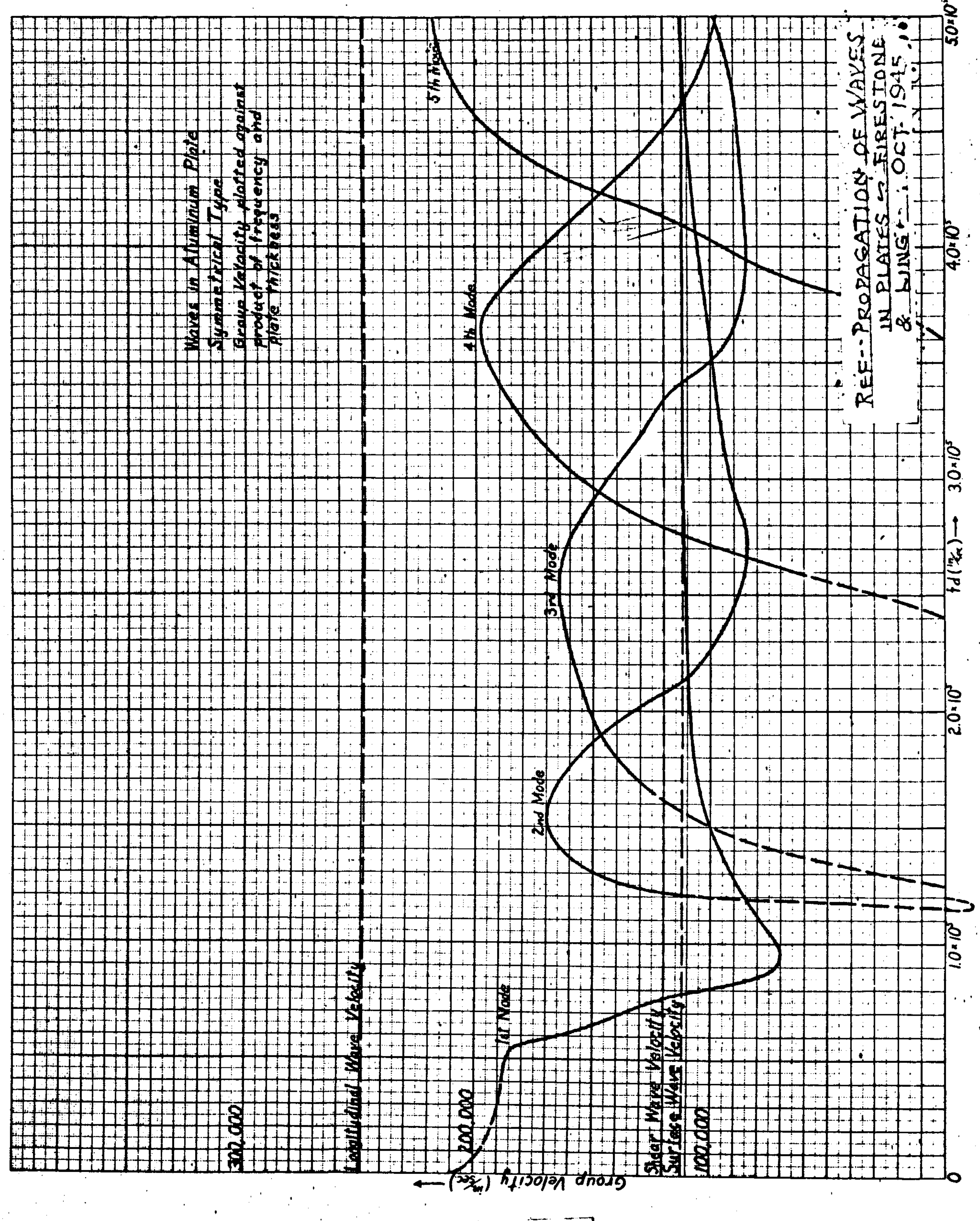
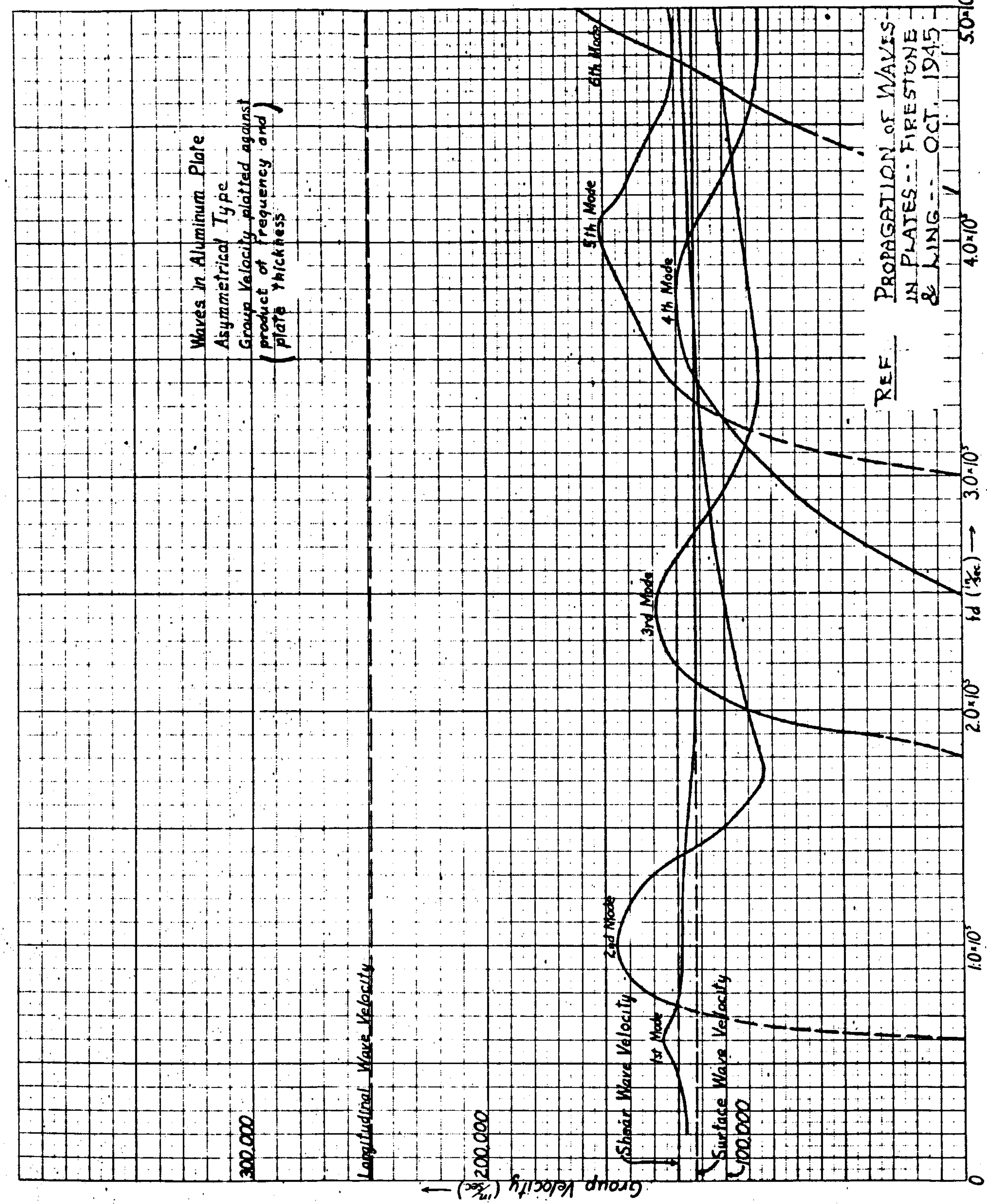

Waves in Aluminum Plate
Symmetrical Type
Group Velocity plotted against product of frequency and plate thickness
Longitudinal Wave Velocity
Shear Wave Velocity
Surface Wave Velocity
1st Mode
2nd Mode
3rd Mode
4th Mode
5th Mode
300,000
200,000
100,000
Group Velocity (in/sec) →
0
1.0×10⁵
2.0×10⁵
3.0×10⁵
4.0×10⁵
5.0×10⁵
fd (in/sec) →
REF.-PROPAGATION OF WAVES IN PLATES - FIRESTONE & LING - OCT. 1945

Figure 23



Waves in Aluminum Plate
Asymmetrical Type
Group Velocity platted against
(product of frequency and plate thickness)
Longitudinal Wave Velocity
Shear Wave Velocity
Surface Wave Velocity
1st Mode
2nd Mode
3rd Mode
4th Mode
5th Mode
6th Mode
300,000
200,000
100,000
Group Velocity (in/sec) →
0
1.0×10^5
2.0×10^5
3.0×10^5
4.0×10^5
5.0×10^5
fd (in/sec) →
REF
PROPAGATION OF WAVES IN PLATES -- FIRESTONE & LING -- OCT. 1945

Figure 24

LAMB WAVE PROPAGATION

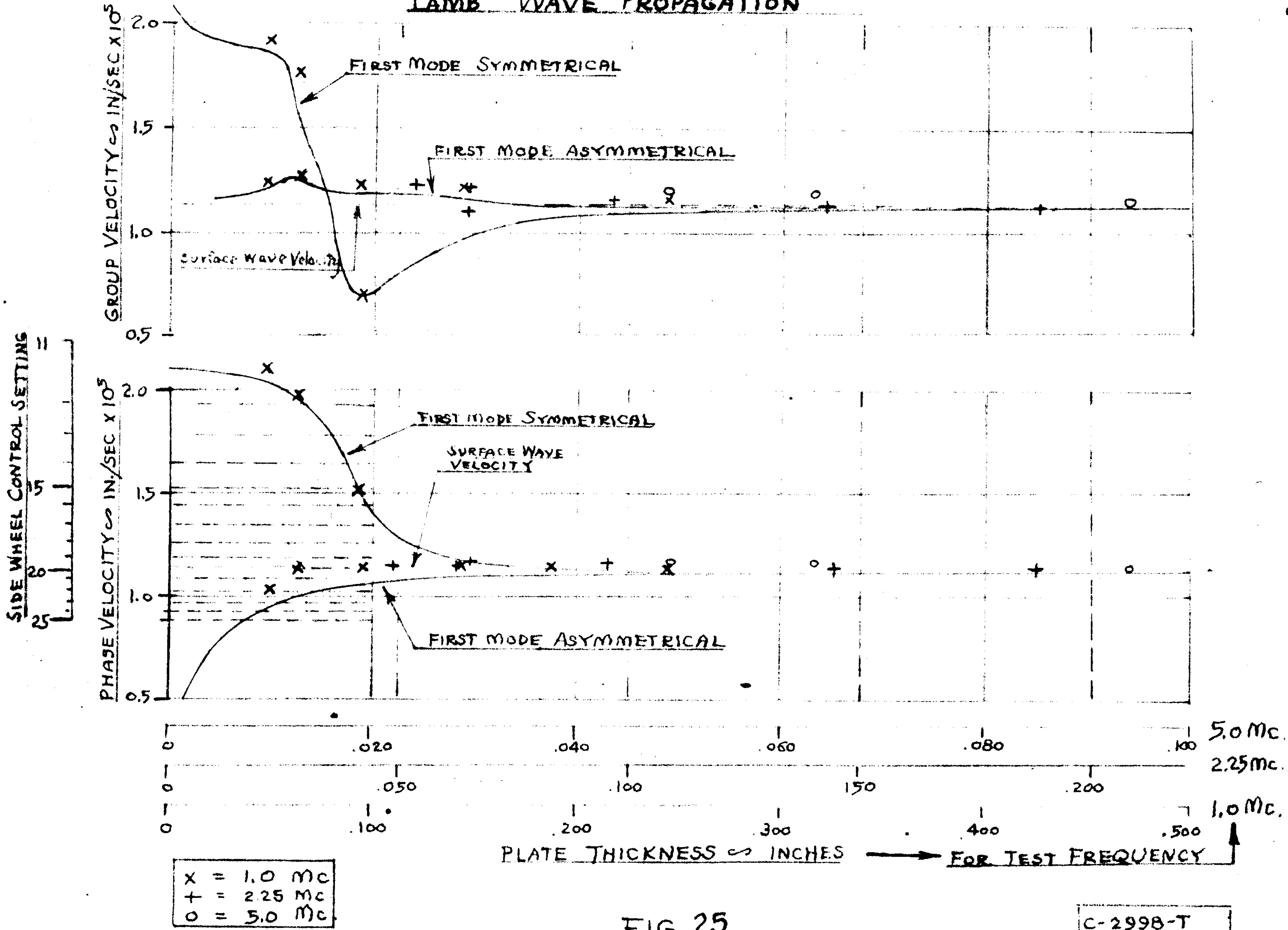
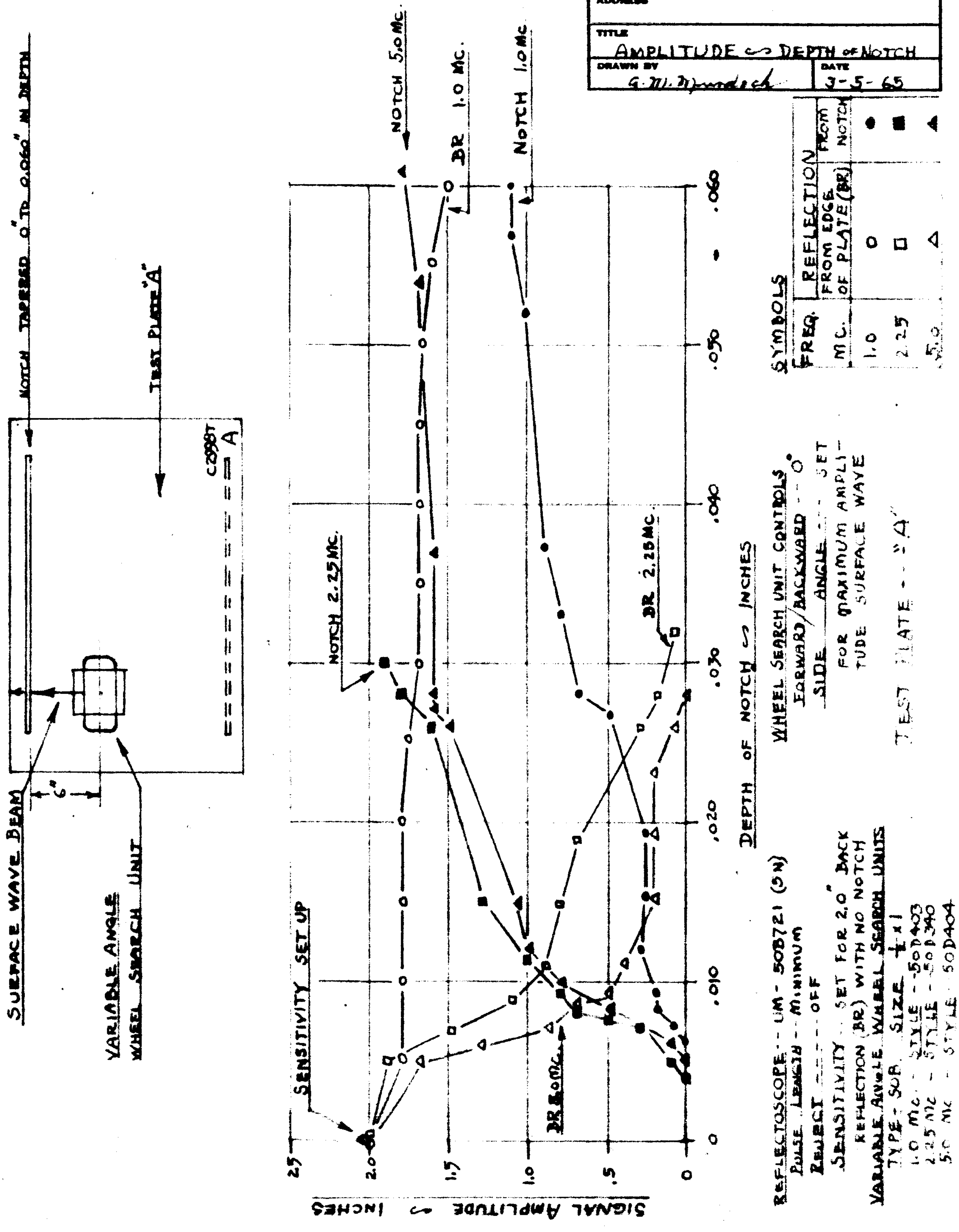


FIG. 25

C-2998-T
1 - 28 - 65
A. McMurdoch

SPERRY PRODUCTS
DIVISION OF AUTOMATION INDUSTRIES, INC.
SKETCH SHEET

SKETCH NO. 26	FILE REF. C-2098-T
CUSTOMER NASA	
ADDRESS	
TITLE AMPLITUDE ~ DEPTH OF NOTCH	
DRAWN BY G. M. Murdock	DATE 3-5-65

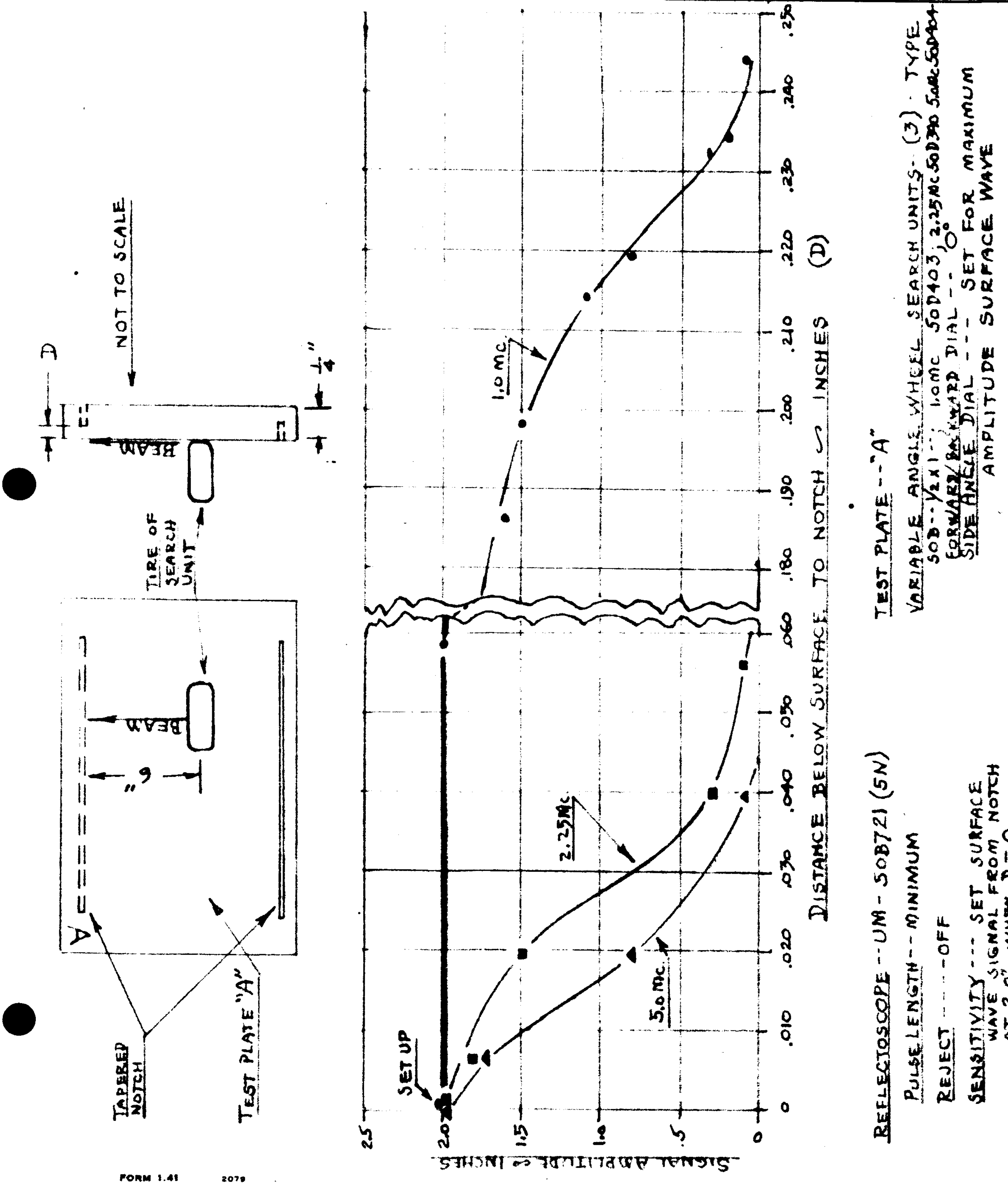


FORM 1.41

19417

SPERRY PRODUCTS
DIVISION OF AUTOMATION INDUSTRIES, INC.
SKETCH SHEET

SKETCH NO. 27	FILE REF. C-2998-T
CUSTOMER NASA	
ADDRESS	
TITLE Sub Surface Notch Study	
DRAWN BY a m Murdoch	DATE 3-15-65

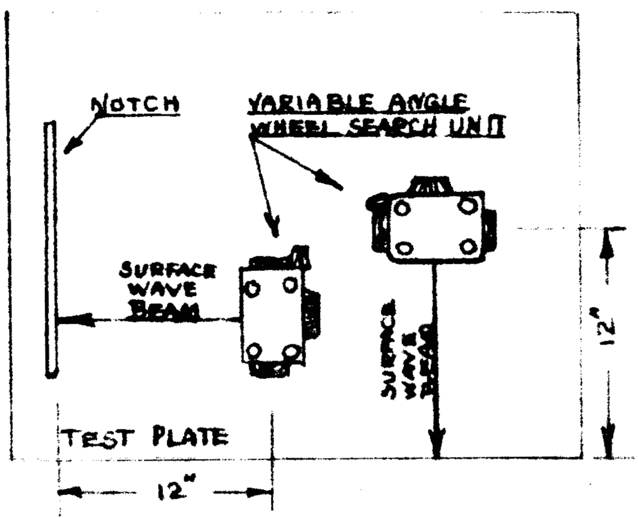


FORM 1.41 2079

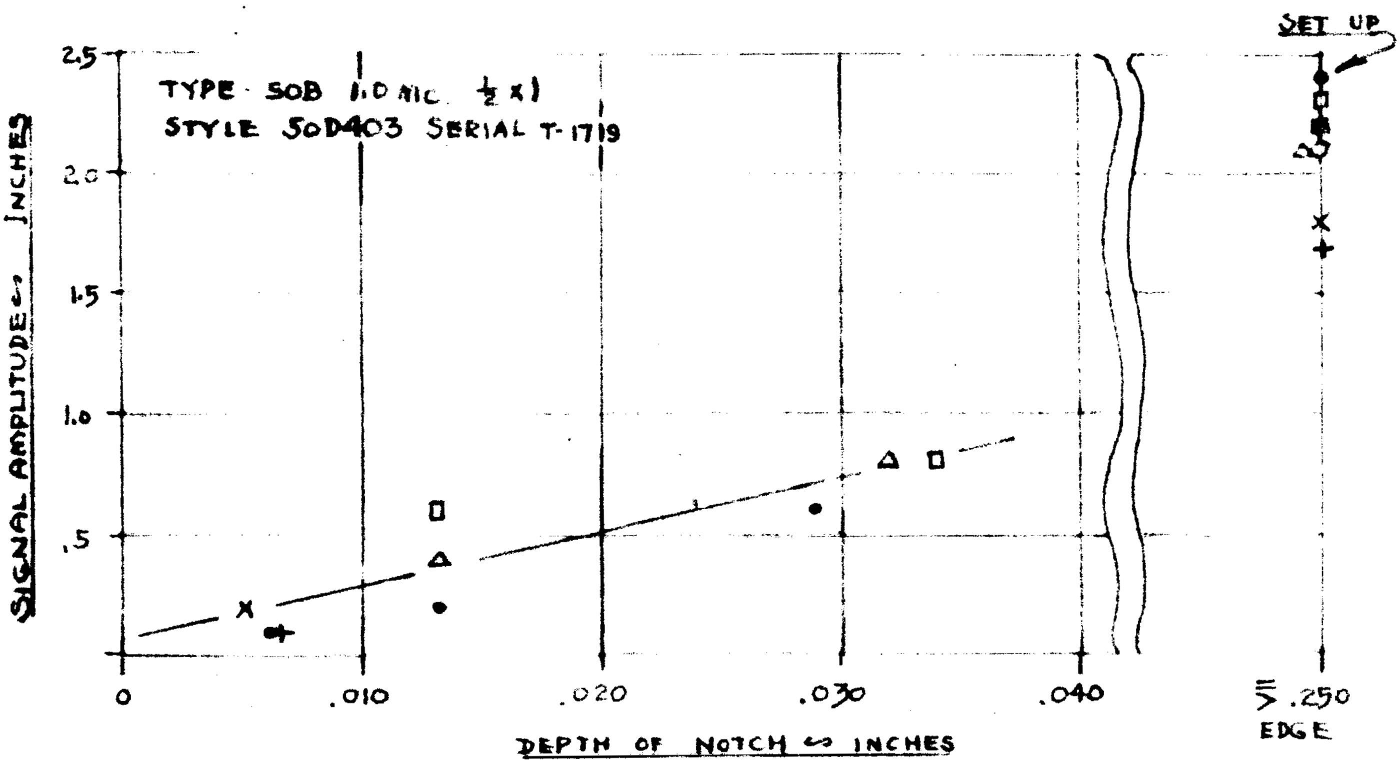
SPERRY PRODUCTS
DIVISION OF AUTOMATION INDUSTRIES, INC.
SKETCH SHEET

SKETCH NO. 28	FILE REF. C-2998-T
CUSTOMER NASA	
SURFACE FINISH STUDY	
TITLE	
DRAWN BY G.M. Meredith	DATE 3-9-65

SEARCH UNIT -- VARIABLE ANGLE WHEEL
WAVE TYPE -- SURFACE
WHEEL SEARCH UNIT CONTROLS
FORWARD/BACKWARD - 0°
SIDE ANGLE -- SET FOR MAXIMUM AMPLITUDE SURFACE WAVE
REFLECTOSCOPE UM-50B721 (SN)
PULSE LENGTH -- MINIMUM
REJECT ------ OFF
SENSITIVITY SET FOR 2.4" SIGNAL FROM EDGE OF PLATE "A"



SYMBOL	PLATE	MAT'L	FINISH
●	A	2219-T37	AS ROLLED
x	D	2219-T37	MILLED, SANDED
+	D	2219-T37	CHEM. MILLED
○	B	2219-T37	MILLED, SANDED, ALODINED
△	E	2219-T87	MILLED, SANDED
□	E	2219-T87	MILLED, SANDED, ALODINED
■	G	2219-T87	FINAL FINISH

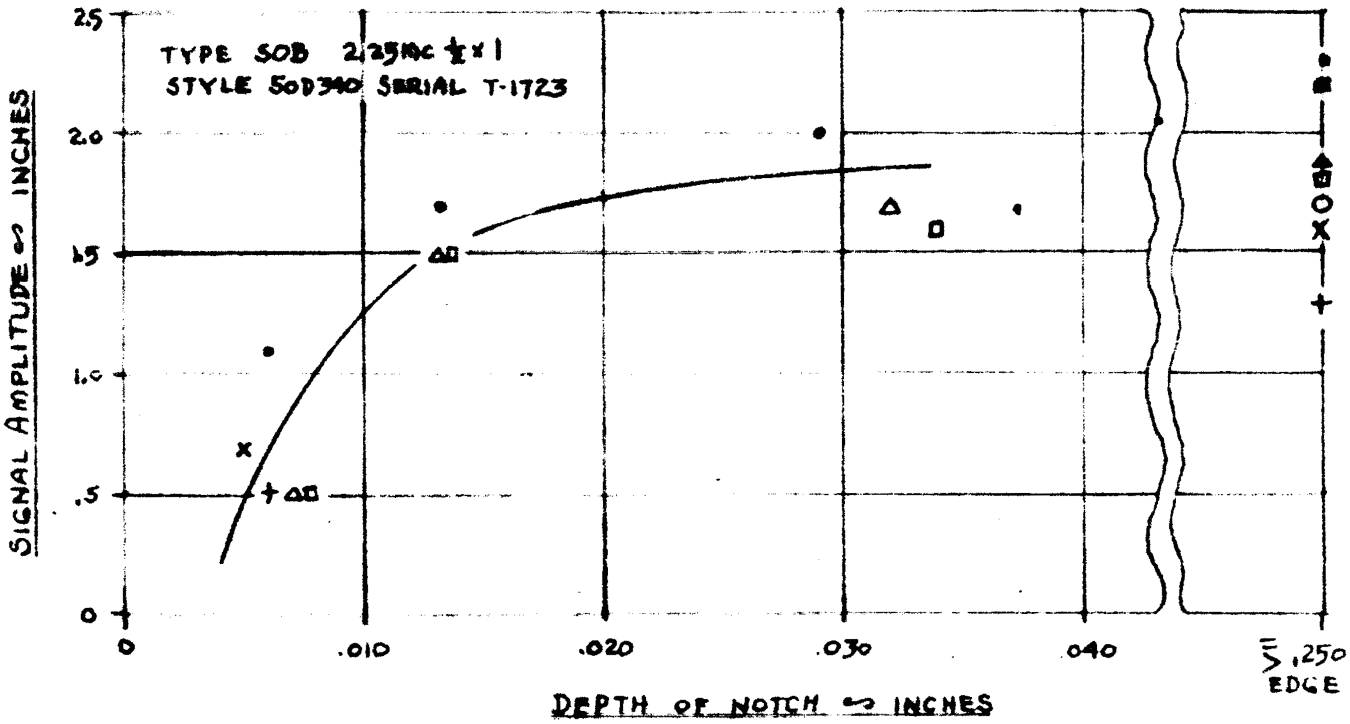


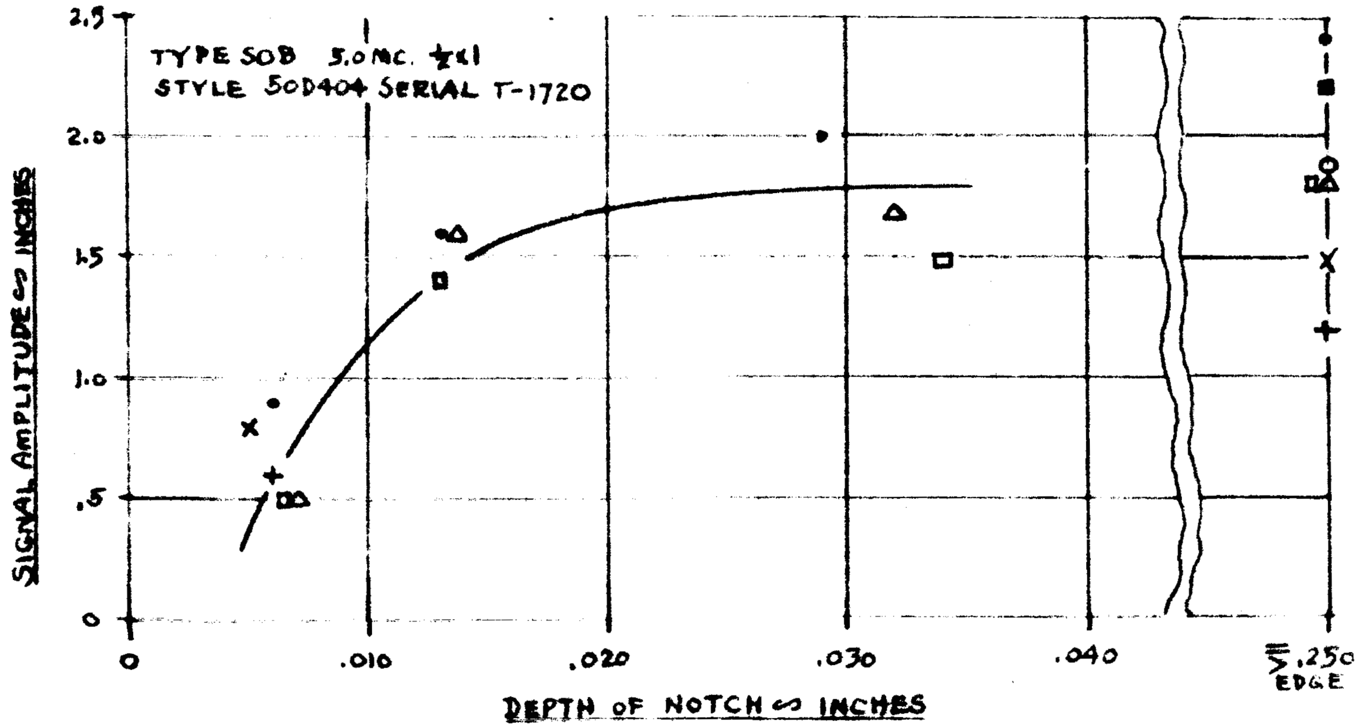
FORM 1:41

19417

SPERRY PRODUCTS
DIVISION OF AUTOMATION INDUSTRIES, INC.
SKETCH SHEET

SKETCH NO. 29	FILE REF. C-2998-T
CUSTOMER NASA	
ADDRESS	
TITLE SURFACE FINISH STUDY	
DRAWN BY G. M. Murdock	DATE 3-9-65





FORM 1.41

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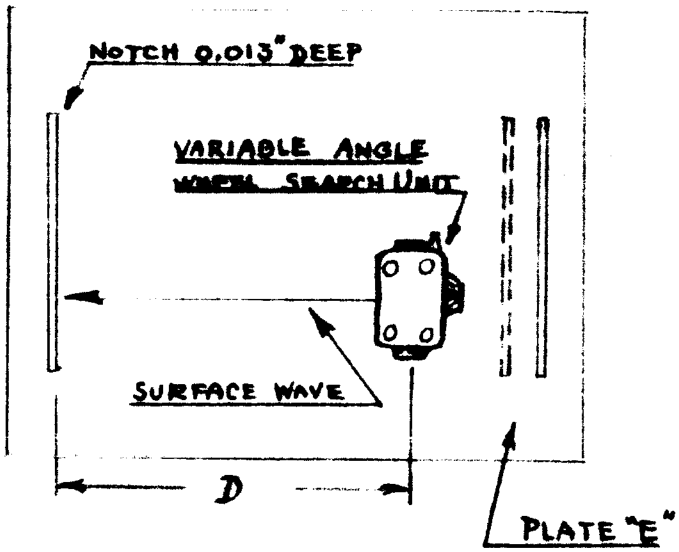
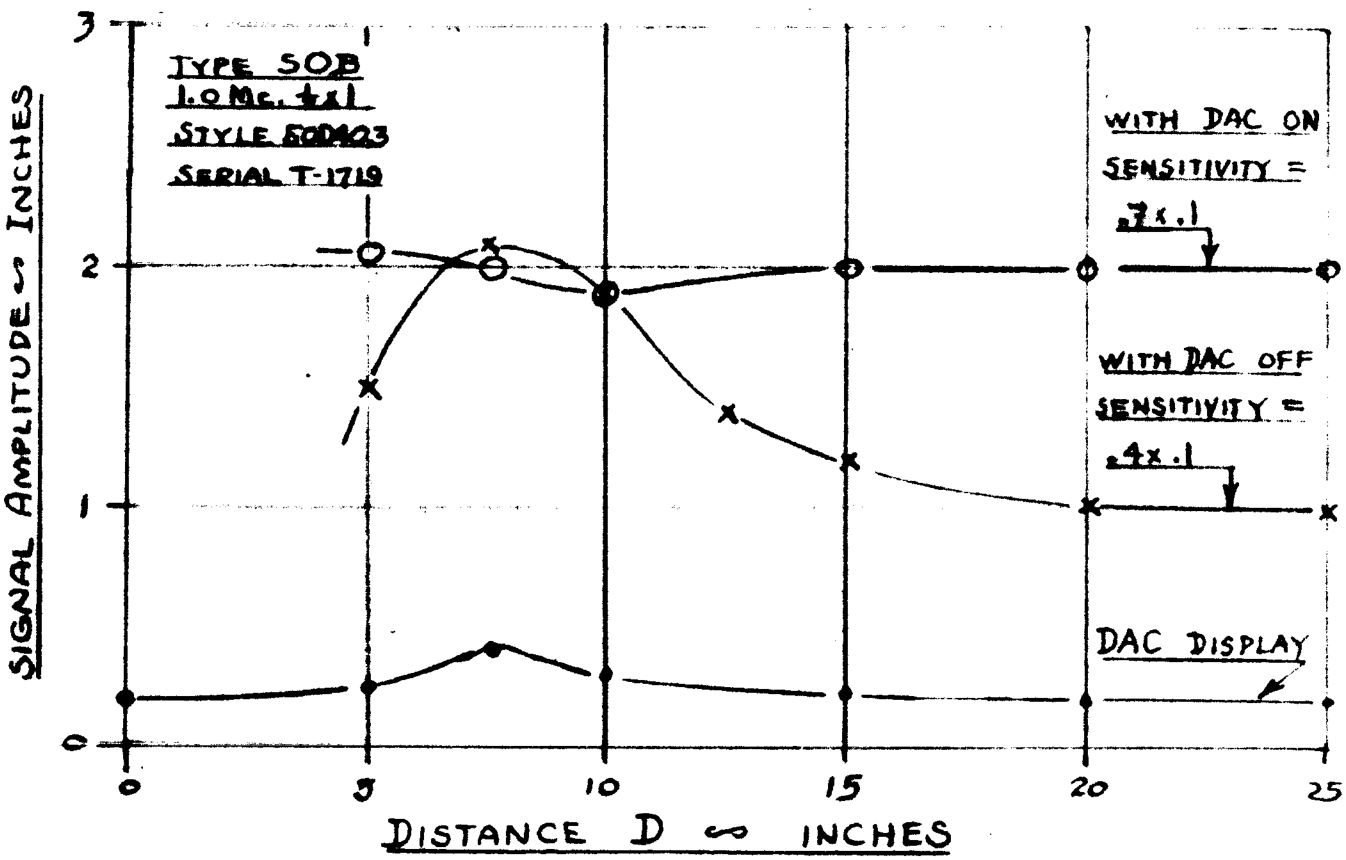
SPERRY PRODUCTS
DIVISION OF AUTOMATION INDUSTRIES, INC.
SKETCH SHEET

SKETCH NO. 30	FILE REF. C2998-T
CUSTOMER NASA	
ADDRESS	
TITLE DAC STUDY	
DRAWN BY G. M. Murdock	DATE 2-26-65



TEST PLATE --- "E"
SEARCH UNIT -- VARIABLE ANGLE WHEEL
SIDE WHEEL CONTROL -- SET FOR PEAK AMPLITUDE SURFACE WAVE REFLECTION FROM 0.013" NOTCH
REFLECTOSCOPE & SETTINGS
TYPE - UM, STYLE 50B721
PULSE LENGTH -- MIN.; REJECT OFF
SENSITIVITY -- SET FOR PEAK SIGNAL AMPLITUDE NOT OVER 2.5"
DAC -- SET FOR FLAT AMPLITUDE - DISTANCE RESPONSE



FORM 1.41

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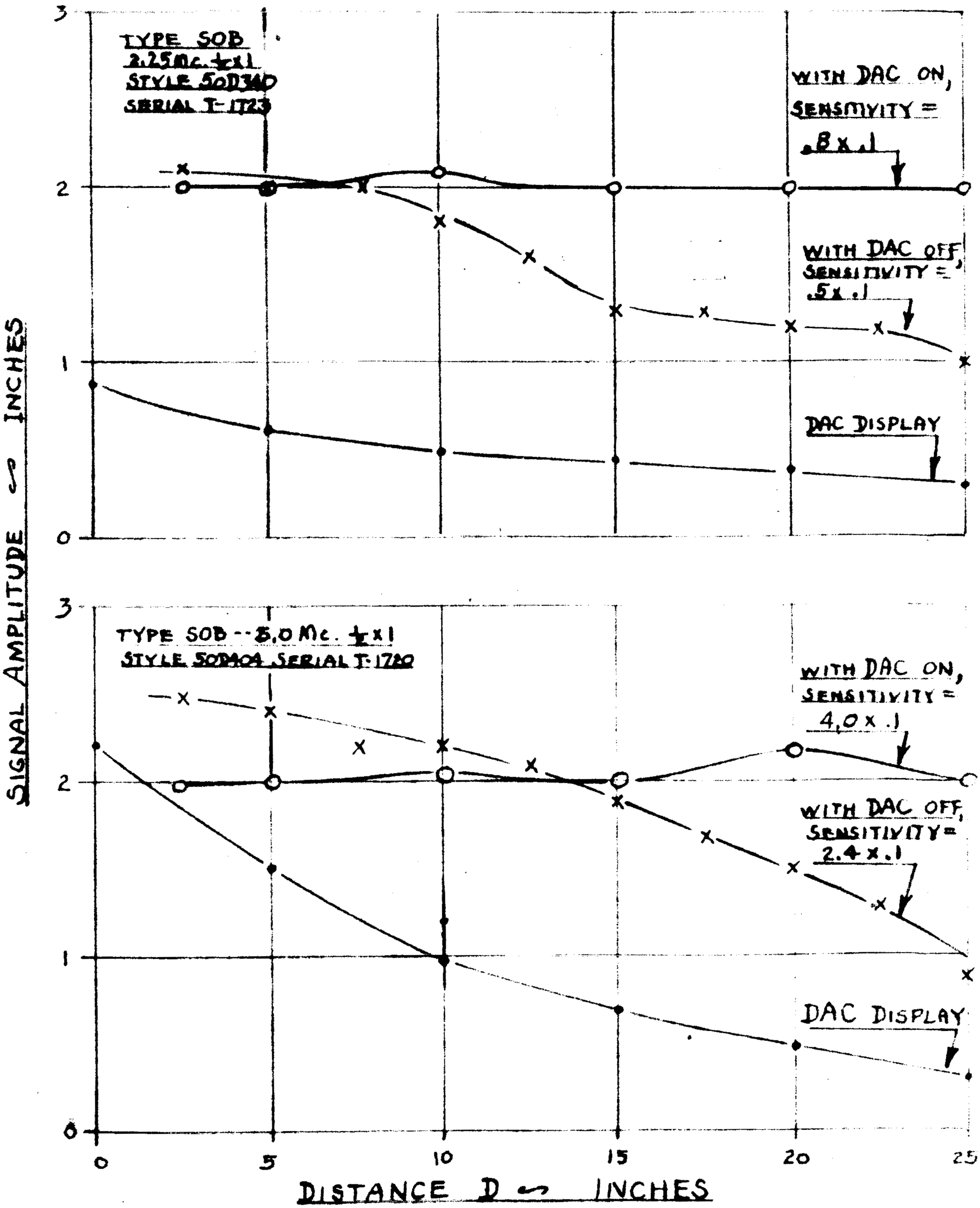
SPERRY PRODUCTS
DIVISION OF AUTOMATION INDUSTRIES, INC.
SKETCH SHEET

SKETCH NO. 31	FILE REF. C-2998-T
CUSTOMER NASA	
ADDRESS	
TITLE DAC STUDY	
DRAWN BY A. M. Murdoch	DATE 2-25 65



FORM 1.41

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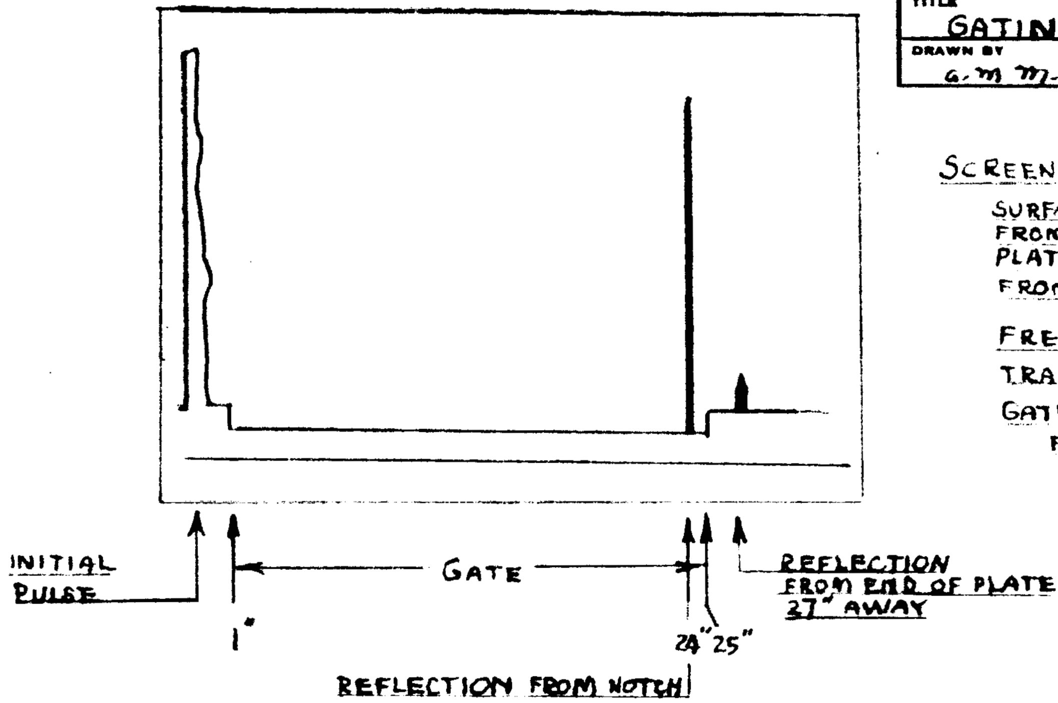
SPERRY PRODUCTS
DIVISION OF AUTOMATION INDUSTRIES, INC.
SKETCH SHEET

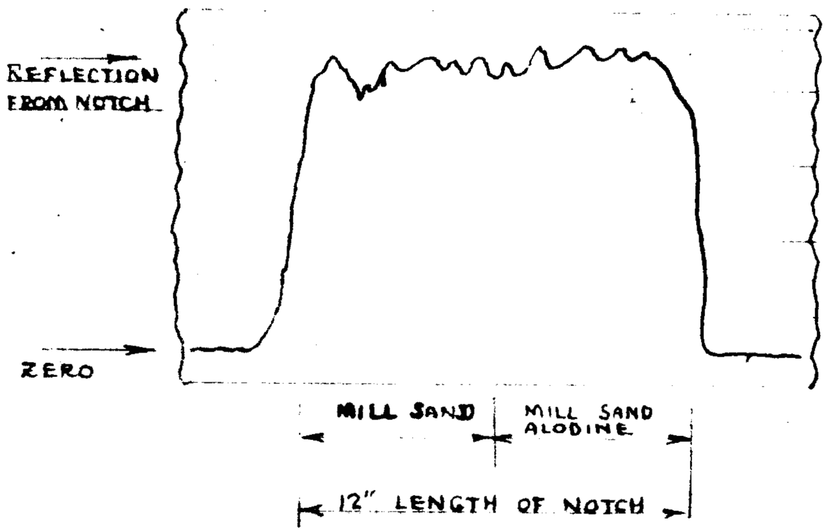
SKETCH NO. 32	FILE REF. C-2998-T
CUSTOMER NASA	
ADDRESS	
TITLE GATING AND RECORDING	
DRAWN BY G. M. Murdoch	DATE 2-26-65



SCREEN PATTERN

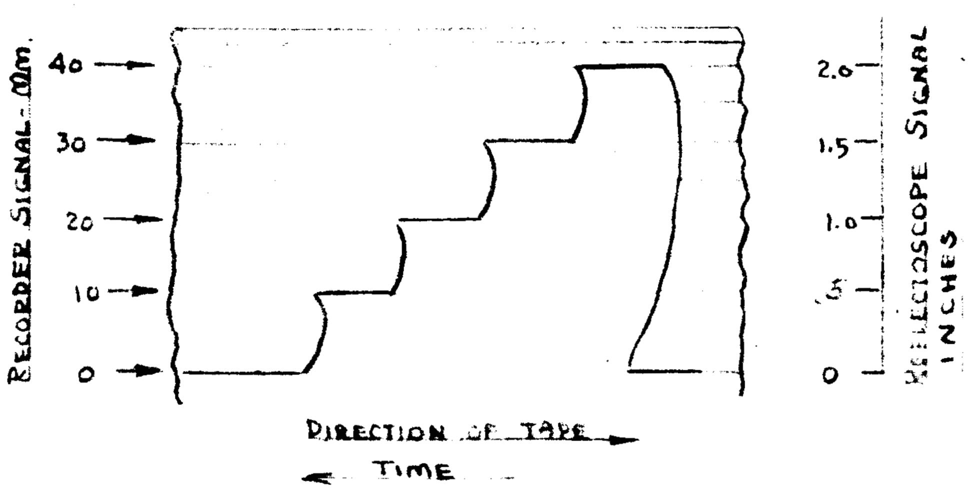
SURFACE WAVE SIGNAL FROM 0.013" NOTCH IN PLATE "E" 24" AWAY FROM CENTER OF TIRE

FREQUENCY - 2.25 Mc
TRANSIGATE - 50E550
GATE - SET 1" TO 25" FROM CENTER OF TIRE



TAPE RECORD

TEST -- SAME AS ABOVE EXCEPT WHEEL ROLLED PARALLEL TO NOTCH DURING RECORDING



TAPE RECORD

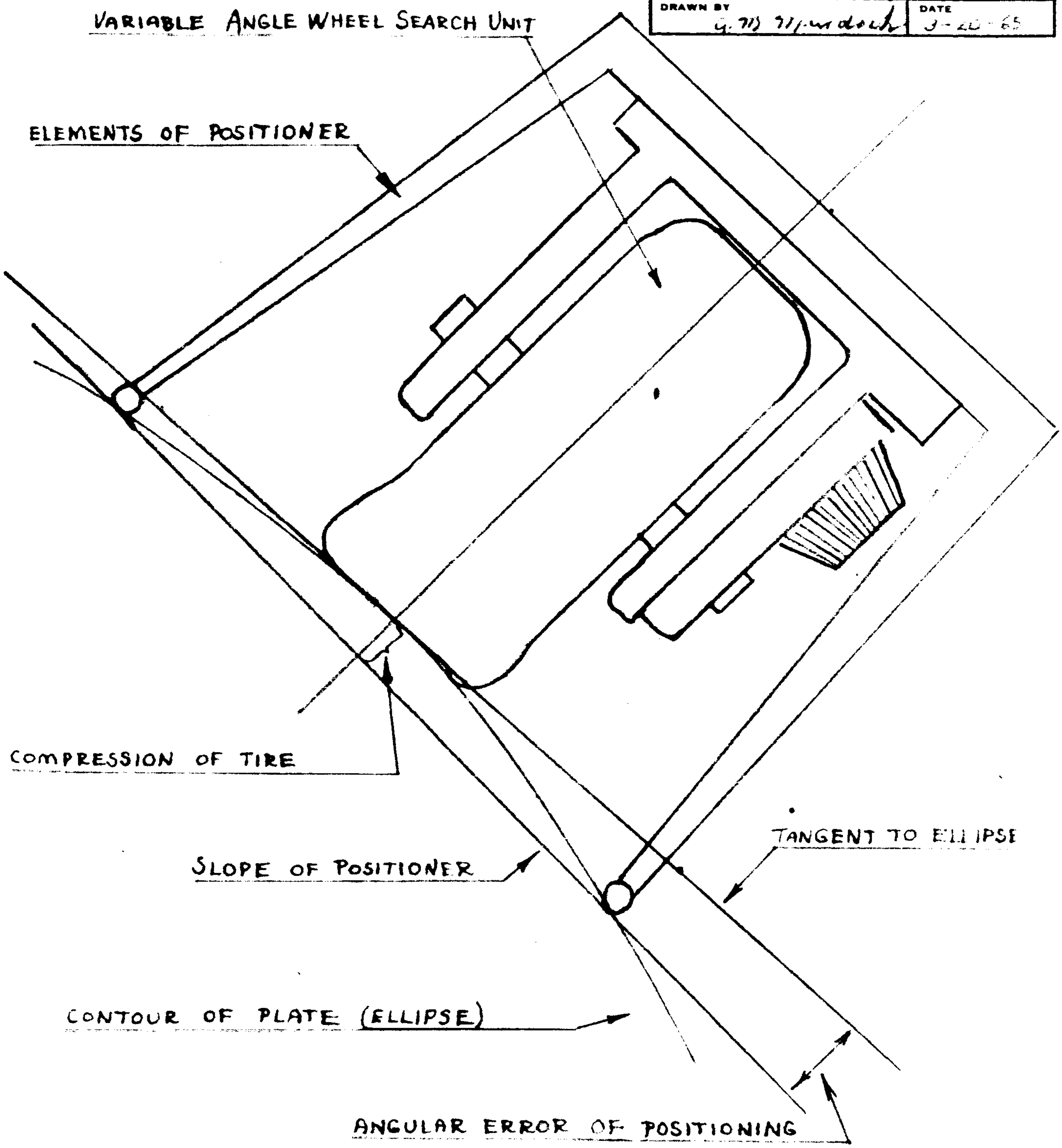
COMPARISON OF REFLECTOSCOPE AND TAPE RECORDER SIGNAL AMPLITUDES

REFLECTOSCOPE - UM 50B721 (5N) & TRANSIGATE 50E550 FREQ. 2.25 Mc. REJECT OFF

RECORDER - BRUSH MARK II, MODEL RD-2522-20

SPERRY PRODUCTS
DIVISION OF AUTOMATION INDUSTRIES, INC.
SKETCH SHEET

SKETCH NO. 33	FILE REF. C-2998-T
CUSTOMER NASA	
ADDRESS	
TITLE SEARCH UNIT ALIGNMENT	
DRAWN BY G. M. Murdoch	DATE 3-20-65



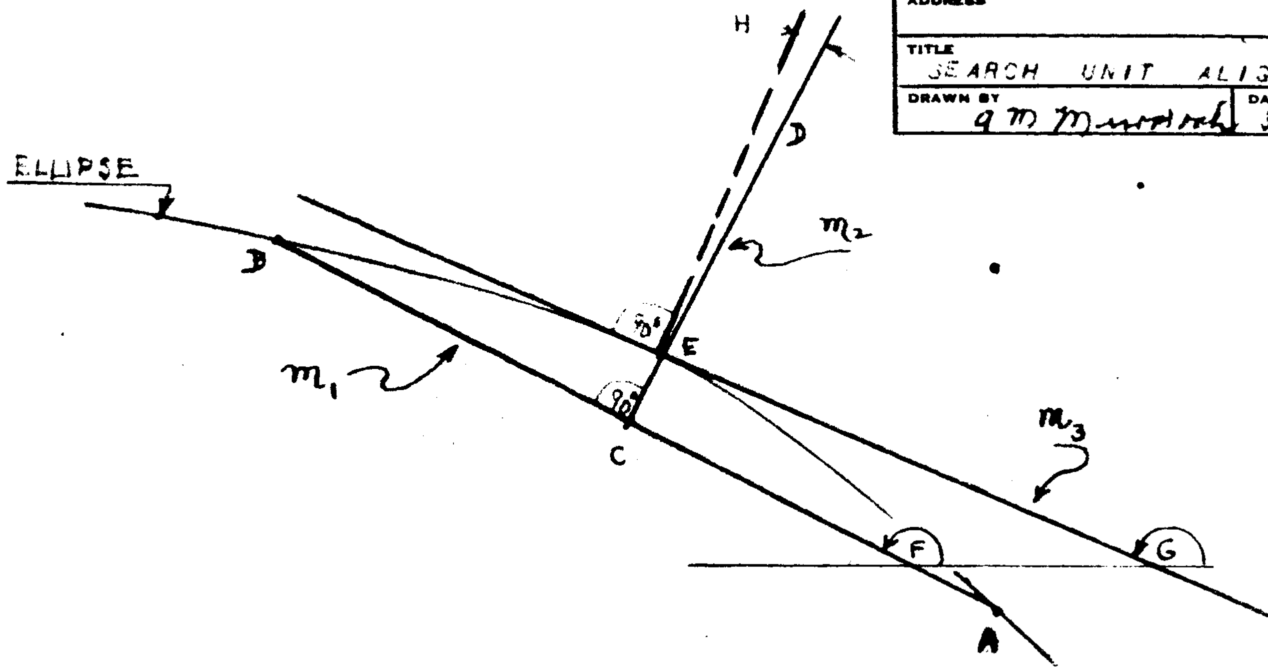
COMPESSION OF TIRE AND ANGULAR ERROR OF POSITIONING ARE IN REFERENCE TO SET-UP ON FLAT PLATE

(NOT TO SCALE)

FORM 1.41

SPERRY PRODUCTS
DIVISION OF AUTOMATION INDUSTRIES, INC.
SKETCH SHEET

SKETCH NO. 34	FILE REF. C 7398 T
CUSTOMER	NASA
ADDRESS	
TITLE	SEARCH UNIT ALIGNMENT
DRAWN BY	G M Murdoch
DATE	3 25 65



ELLIPSE $\overline{AEB}$	$\frac{X^2+2Y^2}{195^2}=1$	EQUATION FOR PLATE CONTOUR
POINT 'A'	COORDINATES (144 , 96.094)	EDGE OF PLATE, LOCATION OF ONE GUIDE POSITIONER
$\overline{AB}$	8 INCHES	DISTANCE BETWEEN GUIDE POSITIONERS
POINT 'B'	COORDINATES FOUND BY SOLUTION OF SIMULTANEOUS EQUATIONS: $\left.\begin{array}{l}\frac{X^2+2Y^2}{195^2}=1\\(X-144)^2+(Y-96.094)^2=8^2\end{array}\right\}$ $X = 137.493$ INCHES, $Y = 100.747$ INCHES	LOCATION OF 2ND GUIDE POSITIONER
M_1	$M_1 = -0.71507$ CALCULATED FROM COORDINATES OF 'A' AND 'B'	SLOPE OF POSITIONER
C	COORDINATES (140.746 , 98.420) CALCULATED FROM COORDINATES OF 'A' AND 'B'	MIDPOINT BETWEEN 'A' AND 'B'
M_2	$M_2 = +1.3984$ CALCULATED FROM M_1 (RECIPROCAL OF M_1 WITH SIGN CHANGED)	

SPERRY PRODUCTS
DIVISION OF AUTOMATION INDUSTRIES, INC.
SKETCH SHEET

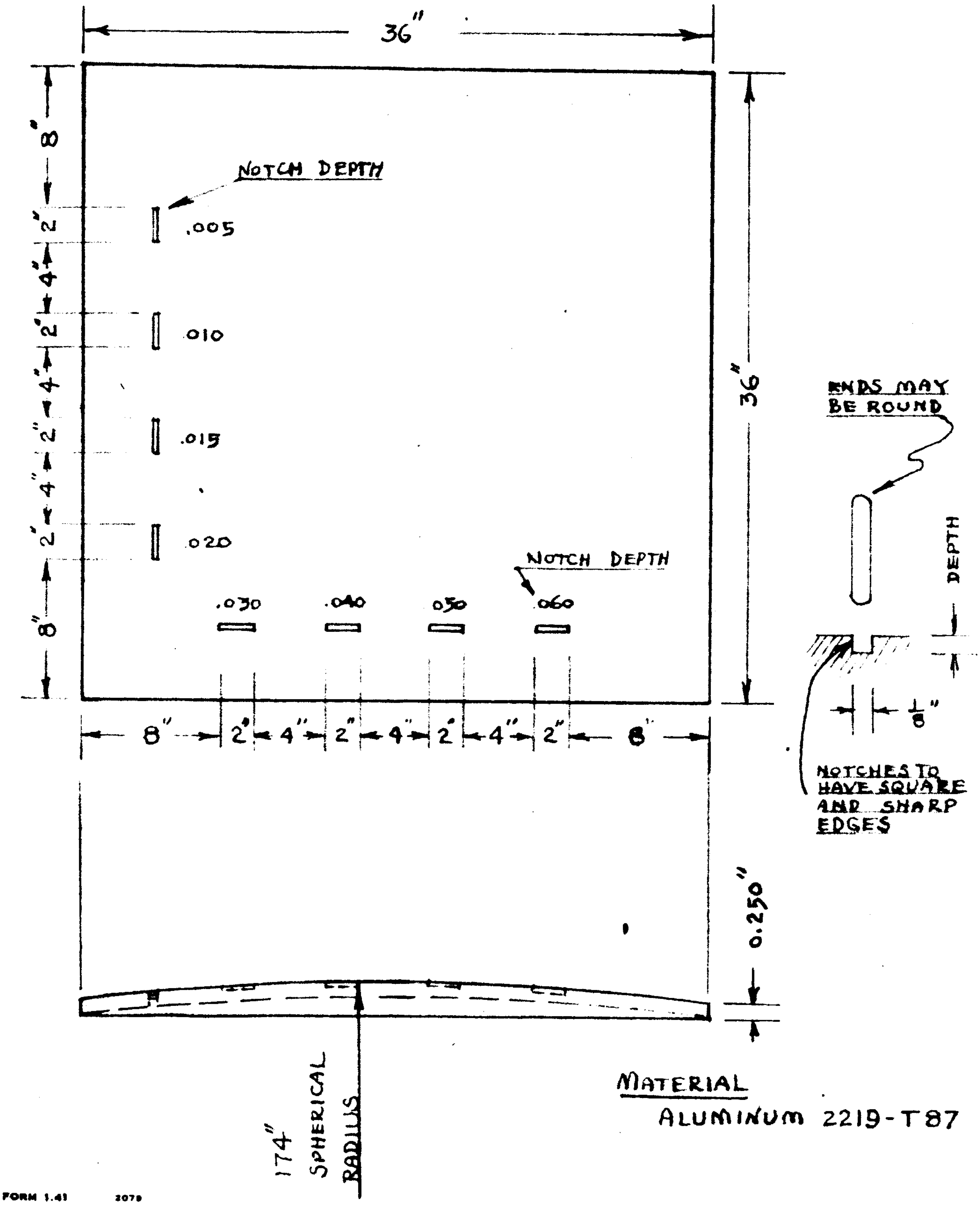
SKETCH NO. 35	FILE C 2993.T
CUSTOMER	
ADDRESS SEARCH UNIT ALIGNMENT	
TITLE	
DRAWN BY G M Murdoch	DATE 3-22-65

LINE $\overline{CD}$	$1.3984\ X - Y = 98.399$ CALCULATED FROM COORDINATES OF POINT 'C' AND FROM SLOPE M_2	CENTERLINE OF TIRE
POINT 'E'	COORDINATES FOUND BY SOLUTION OF SIMULTANEOUS EQUATIONS : $$\left.\begin{aligned}\frac{X^2 + 2Y^2}{198^2} &= 1 \\ 1.3984\ X - Y &= 98.399\end{aligned}\right\}$$ $X = 140.75$ $Y = 98.440$	INTERSECTION OF CENTERLINE OF TIRE AND ELLIPSE
M_3	$\frac{X^2 + 2Y^2}{198^2} = 1$ $\frac{DY}{DX} = -\frac{X}{2Y}$ WHEN $X = 140.76$ $M_3 = -\frac{140.76}{196.880}$ $M_3 = -0.71495$	EQUATION FOR THE ELLIPSE FIRST DIFFERENTIAL SLOPE OF PLATE AT CENTER OF TIRE CONTACT
ANGULAR ERROR OF POSITIONING 'H'	$TAN\ F = M_1$ $TAN\ F = -0.71507$ $F = 144° \ 25.95'$ $TAN\ G = M_3$ $TAN\ G = -0.71495$ $G = 144° \ 26.33'$ $H = (G - F) = 0.28'$	ANGLE BETWEEN CENTERLINE OF TIRE AND A NORMAL TO PLATE SURFACE AT CENTER OF TIRE CONTACT
LINE $\overline{CE}$	DISTANCE "C" TO "E" = 0.024 INCH CALCULATED FROM COORDINATES OF POINTS 'C' AND 'E'	COMPRESSION OF TIRE

SPERRY PRODUCTS
DIVISION OF AUTOMATION INDUSTRIES, INC.

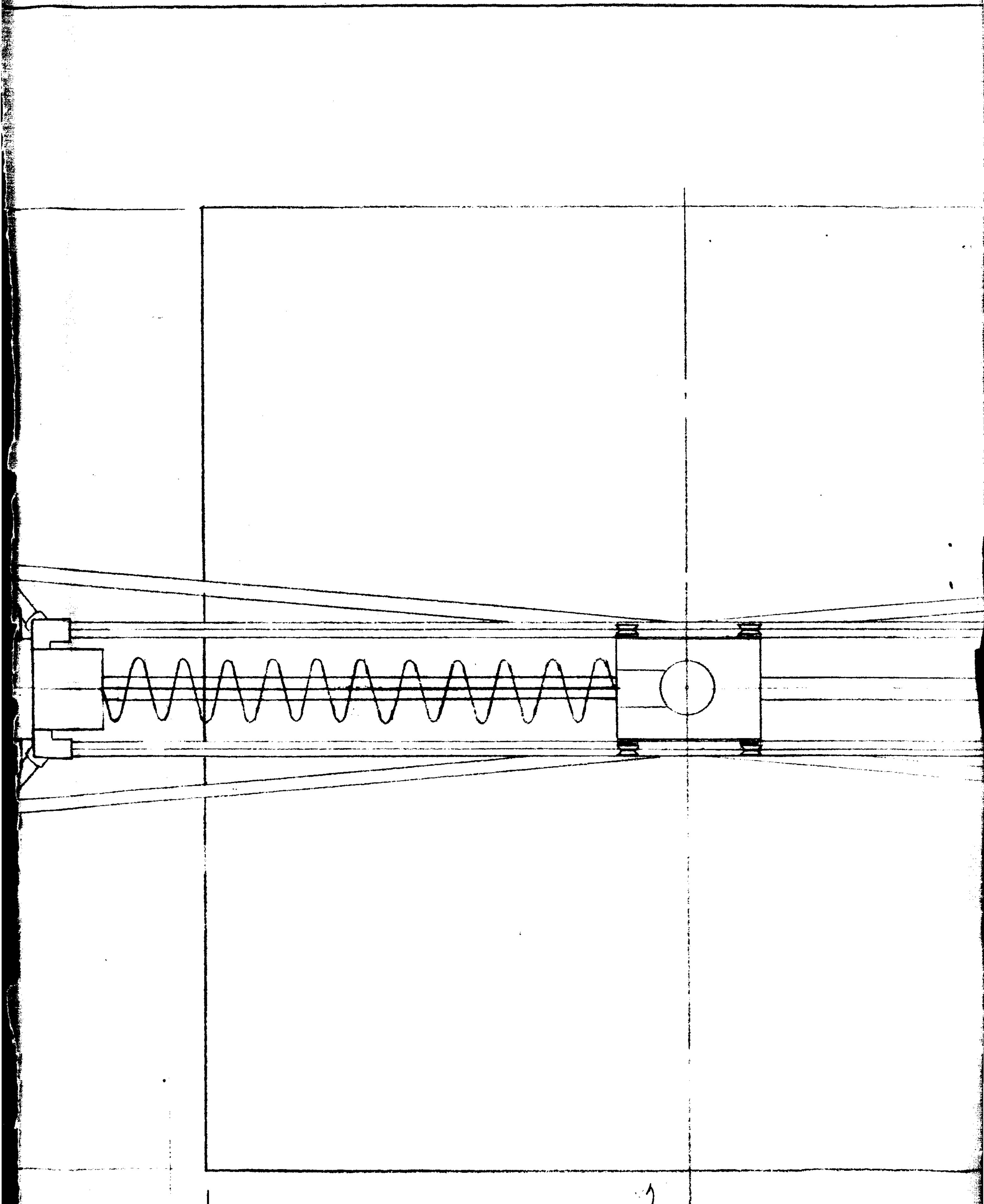
SKETCH SHEET

SKETCH NO. 37	FILE REF. C-2998-T
CUSTOMER NASA	
ADDRESS	
TITLE TEST PLATE	
DRAWN BY G. M. Murdoch	DATE 3-17-65

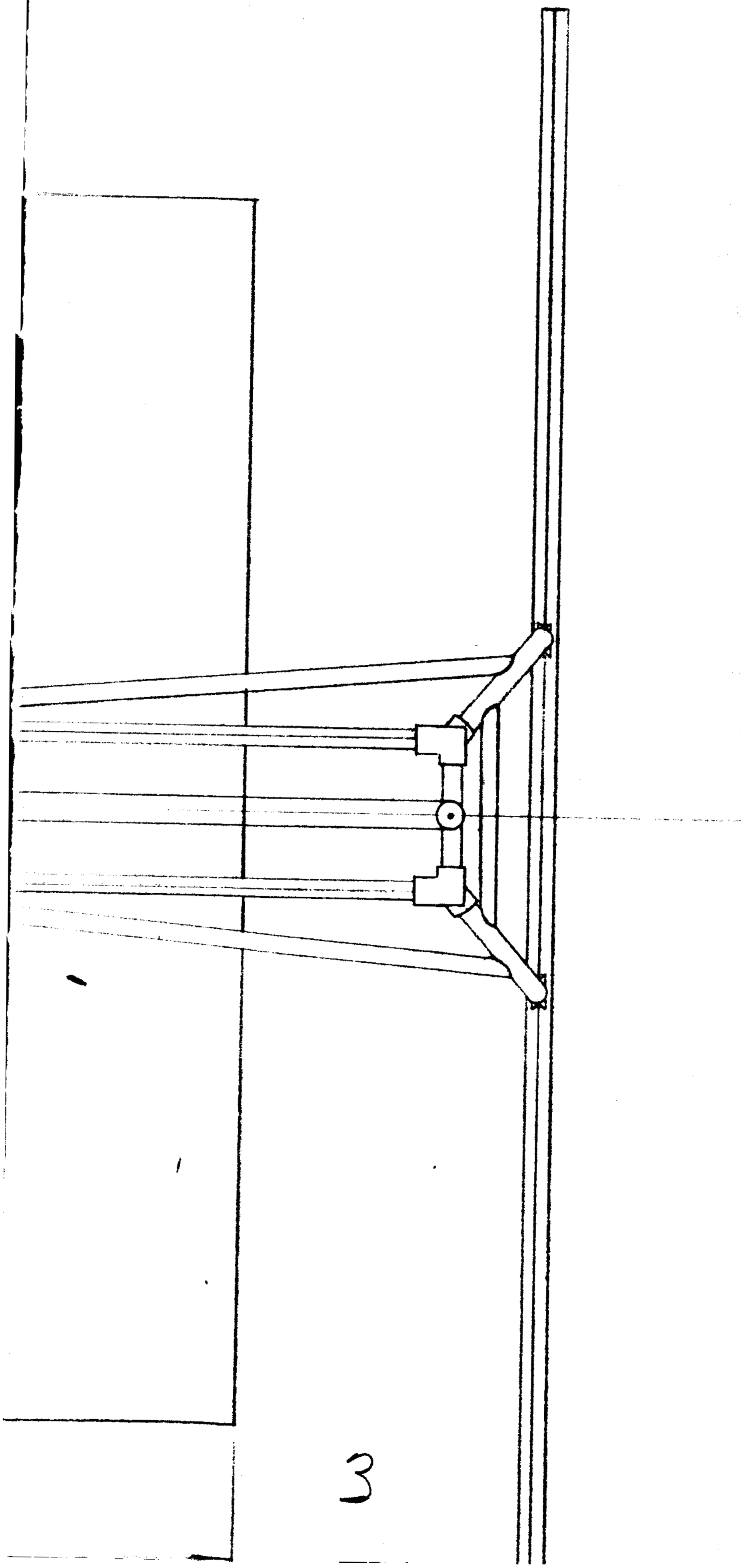


MATERIAL

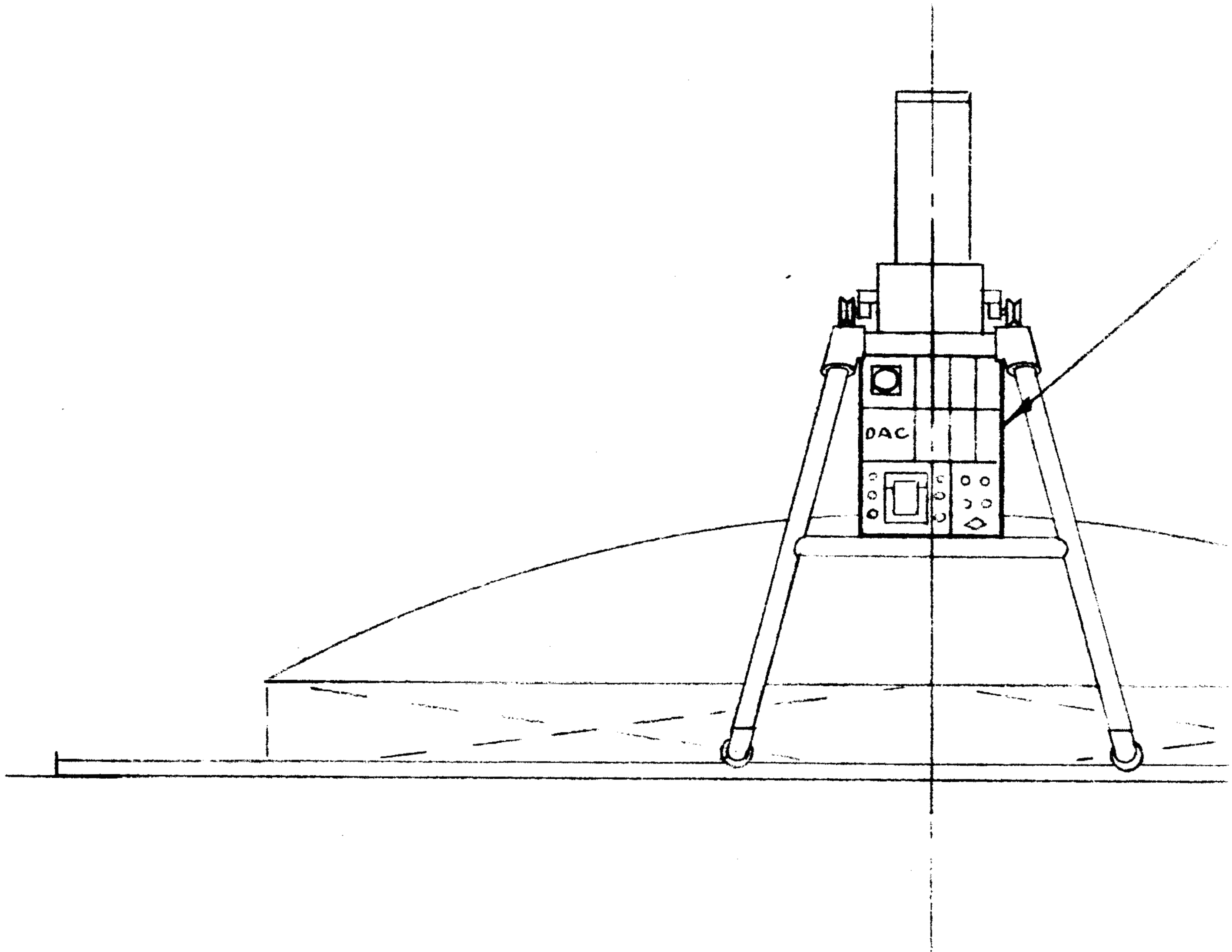
ALUMINUM 2219-T87

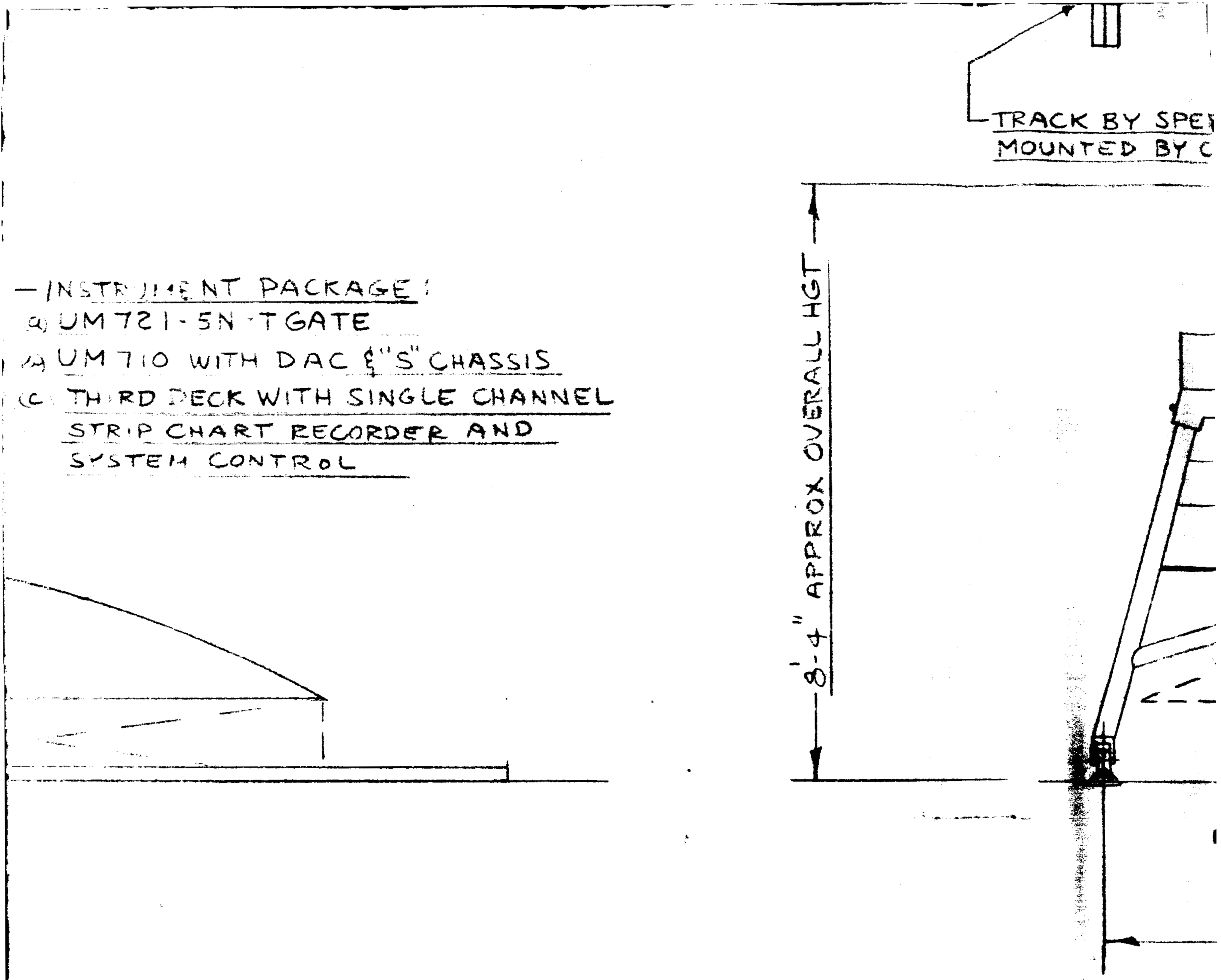


2



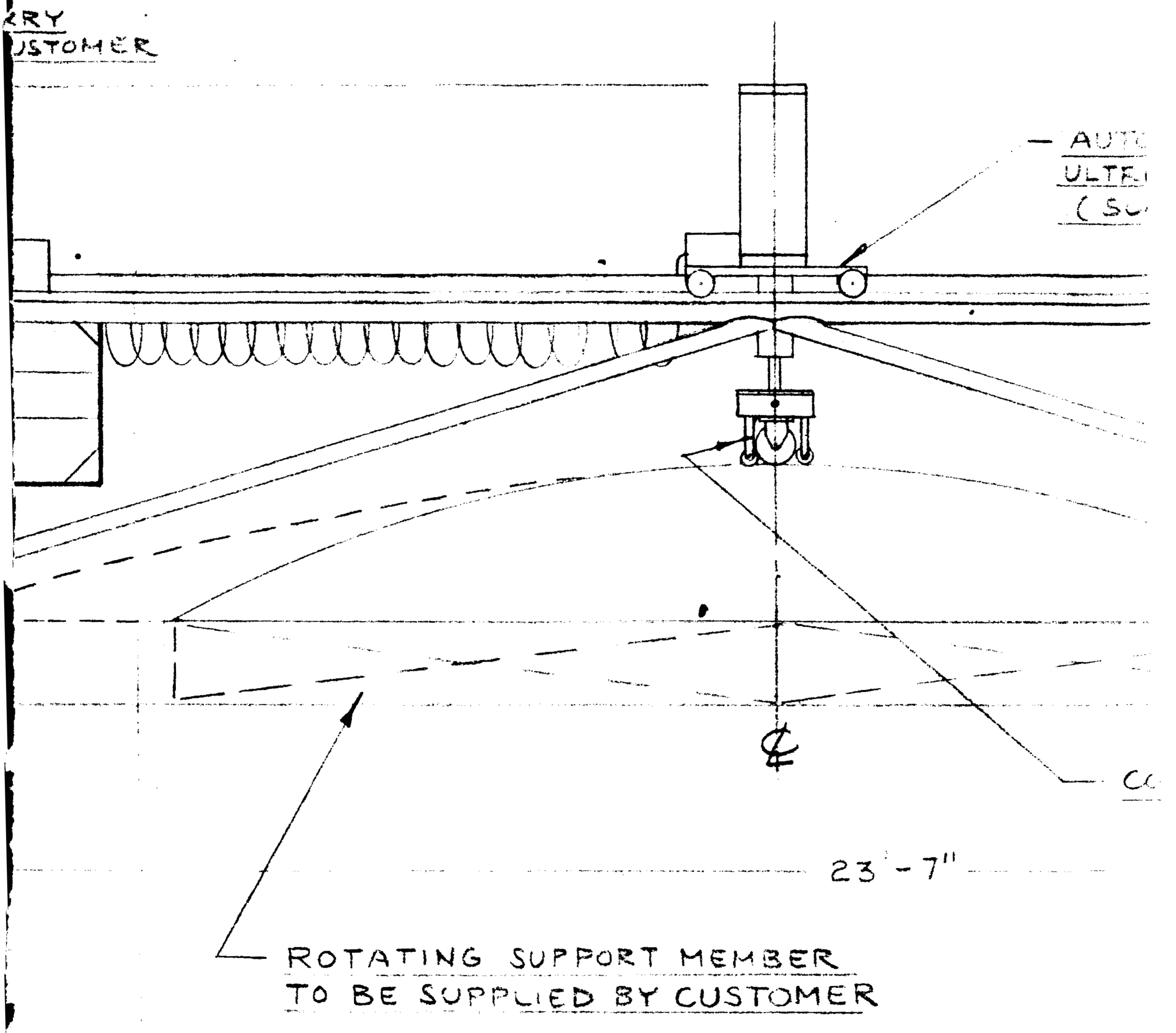
3


DAC



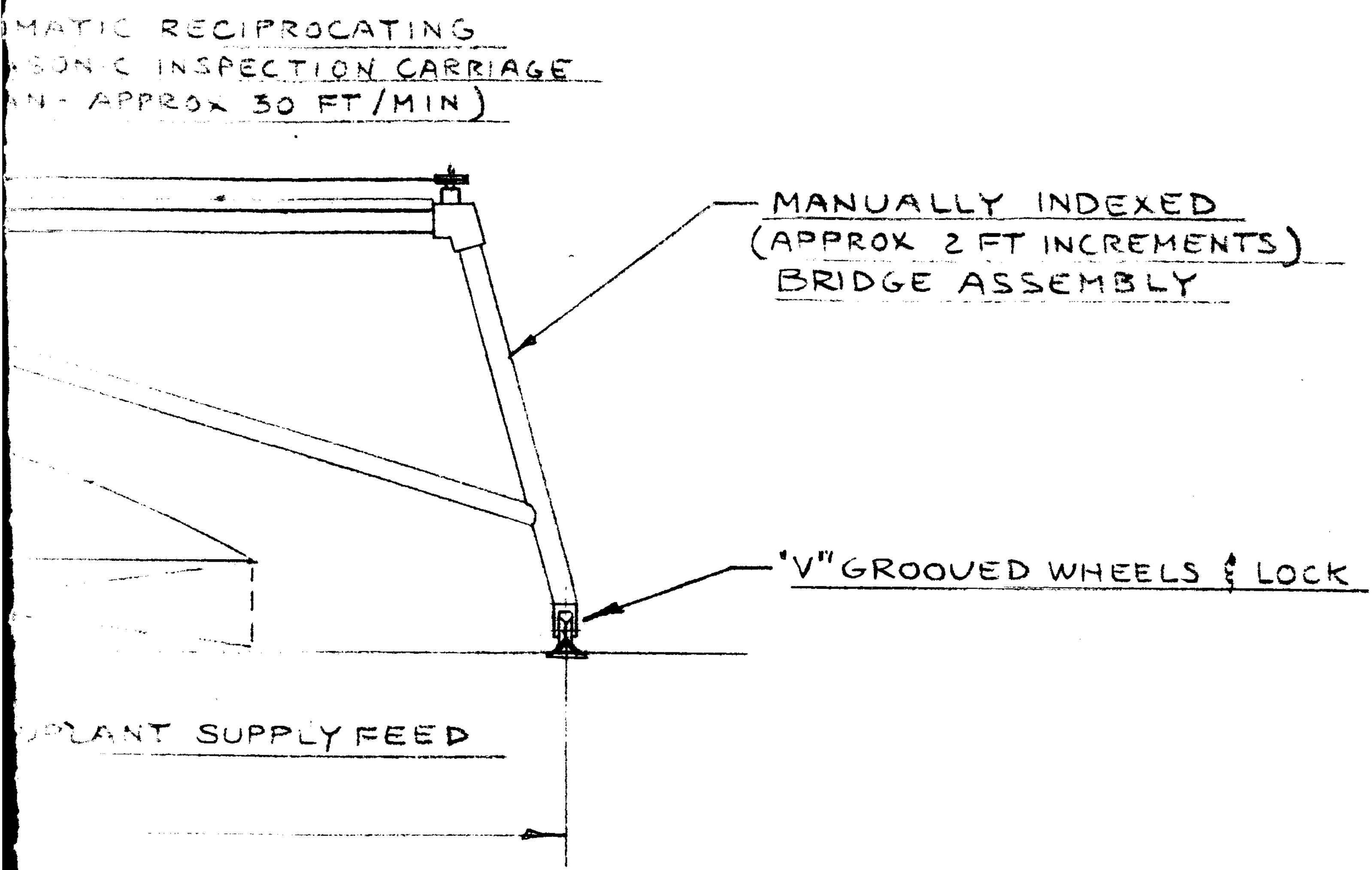
NOTE:

1. CUSTOMER TO SUPPLY
   (A) 80 P.S.I.-AIR
   (B) 115 VAC 60 CYCLE - ELECTRIC
   (C) COUPLANT MAKEUP



RY
USTOMER
AUT
ULTR
(SU
23'-7"
CO
ROTATING SUPPORT MEMBER
TO BE SUPPLIED BY CUSTOMER

FIG 36



ITEM NO.	DWG. OR PART NO.	NAME	QUAN. REQ.

BILL OF MATERIAL

CHK.		
DATE		
E.C.N. NO.		
LTR.	ENG. REF.	TIMES USED

SCALE $\frac{1}{2}$" = 1'-0"
EXCEPT AS NOTED
DEC. ± —
FRAC. ± —
ANGLES ± —
MACH. ✓
DEBURR & BREAK SHARP EDGES & CORNERS

REF. ASS'Y. NO. —

MAT. OR P. SPEC. 7 —

FINISH

AUTOMATION INDUSTRIES, INC.
SPERRY PRODUCTS DIVISION
DANBURY, CONNECTICUT • U.S.A.

PROPOSED SYSTEM FOR SURFACE WAVE INSPECTION

Sperry 52D311

DRAWN BY [signature] DATE 3-14-65
CHECKED BY [signature] DATE 3-15-65
APPROVED BY [signature] DATE 3/23/65
MFG. CHECK BY DATE

52D311